WATER QUALITY IN THE GREAT LAND
ALASKA'S CHALLENGE

PROCEEDINGS

Ronald G. Huntsinger
Technical Chairman

Alaska Section
American Water Resources Association

Water Research Center
Institute of Northern Engineering
University of Alaska Fairbanks
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ADMINISTERING WATER QUALITY MANAGEMENT PROGRAMS

THE POLITICS OF WATER QUALITY IN ANCHORAGE, ALASKA

by Rodman Wilson, M.D.[1], and J. David Norton, P.E.[2]

ABSTRACT

The Municipality of Anchorage is in the forefront of new and innovative approaches to water quality management that are both environmentally sound and economically achievable.

The implementation and administration of a management plan is far reaching and complex. Identification and development of methods to enlighten the public as well as guide agencies to respond in areas of financing schemes, capital construction, maintenance practices, flood protection, erosion and sedimentation control, water quality monitoring, and various regulation is necessary to achieve the comprehensive tasks involved.

INTRODUCTION

Although the Municipality of Anchorage encompasses an area of approximately 1,950 square miles, only about 15 percent of the area is developable (Municipality, 1980).

The urban area of the municipality is crossed by several streams and their floodplains. Historically, emphasis on community growth had been placed upon land development with little regard toward drainage and its impact on local streams and aquifers. Unbridled development has turned local streams into posted health hazards. School children are now familiar with terms like "contamination," "degradation," and "coliform"--great for their vocabulary, but tough on the environment.

Public attitudes and practices contributed to surface and ground water problems. The Municipality of Anchorage looked to the public for solutions.

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HISTORY

There had been sporadic concern about contamination of surface and ground water in Anchorage in the 1950's, but public perception was that Anchorage was still a small town and that problems with water were self-correcting. Anchorage Borough Mayor John Asplund almost single-handedly got the first modern gravity sewer system started in the 1960's. Tax dollars were necessary to perform that undertaking, but the public was, in general, unaware of the impending fate of their waterways despite Mayor Asplund's foresight.

The environmental issues of the 1970's gave way to a realization in the 1980's that stresses of urbanization on water quality happen even in Alaska, especially in Anchorage. An Investigation of Surface Water Quality in Four Selected Streams Within the Anchorage Urban Area (State of Alaska, 1981) became the catalyst that brought water quality to the forefront of the public eye. This working paper, released in late August 1984, by the Alaska Department of Environmental Conservation, analyzed data gathered in 1981-1982. Documentation of gross contamination of Campbell Lake, Westchester Lagoon, Campbell, Little Campbell, Chester, and Fish Creeks moved the press and the public to make the issue political. The report created much furor just prior to Mayor Tony Knowles' reelection in October 1984.

Earlier in 1984, a citizens group had organized as The Anchorage Coalition for Clean Streams and by fall became the Anchorage Waterways Council. This fine organization has led the way by voice, action, and gadfly stabs at government, and should be credited for much good with respect to water quality in Anchorage.

Another group, the Knik Kanoers and Kayakers, Inc., began to raise concern publicly about the quality of Eagle River water. By the fall and winter of 1984, this group was well into a written lobbying effort with legislators and Mayor Knowles.

Public attitude began to change from indifference to concern. Water quality broadened from a recreation-oriented issue to a health matter of concern to the general public. In November 1984, a group of private and governmental people concerned about water began to meet at the Municipality of Anchorage Department of Health and Human Services (DHHS), and by January 1985, the Waterways Technical Advisory Committee was officially appointed by Mayor Knowles. Under the chairmanship of John Franklin, then Commissioner of Public Safety for Anchorage, the Committee produced a report in March, Recommendations to Enhance the Surface Waters of Anchorage (Waterways Technical Advisory Committee, 1985). This document led directly to DHHS's posting selected steams and lakes in Anchorage as polluted.

In February and early March 1985, high school students, organized through the Anchorage Waterways Council and DHHS, walked five Anchorage streams. They collected water samples and marked grossly soiled spots along the way. Public awareness began to emerge through education.

In April 1985, Governor Sheffield granted Anchorage $110,000 in emergency funds for laboratory testing of waters suspected of being polluted. In May 1985, cancellation of an annual float race, the highly popular Campbell Creek Classic, became a noteworthy event in consolidating public awareness.

In early June 1985, Mayor Knowles, accompanied by a retinue of functionaries and reporters, toured the sadly soiled creeks and lakes. Shortly thereafter, by executive order, the mayor created the Water Quality Council as an intragovernmental device to implement solutions to the water pollution problem. The council consisted of the heads of the five municipal departments that dealt with water: Public Works, Parks and Recreation, Water and Wastewater Utility, Health and Human Services, and Community Planning. The principal health official was chairman of the council with the director of Intergovernmental Affairs appointed as vice chairman. The explicit aim of the council was to get departments to work in concert to clean surface and subsurface waters (Figure 1). June also marked the granting of another $200,000 from the governor for surface water enhancement.

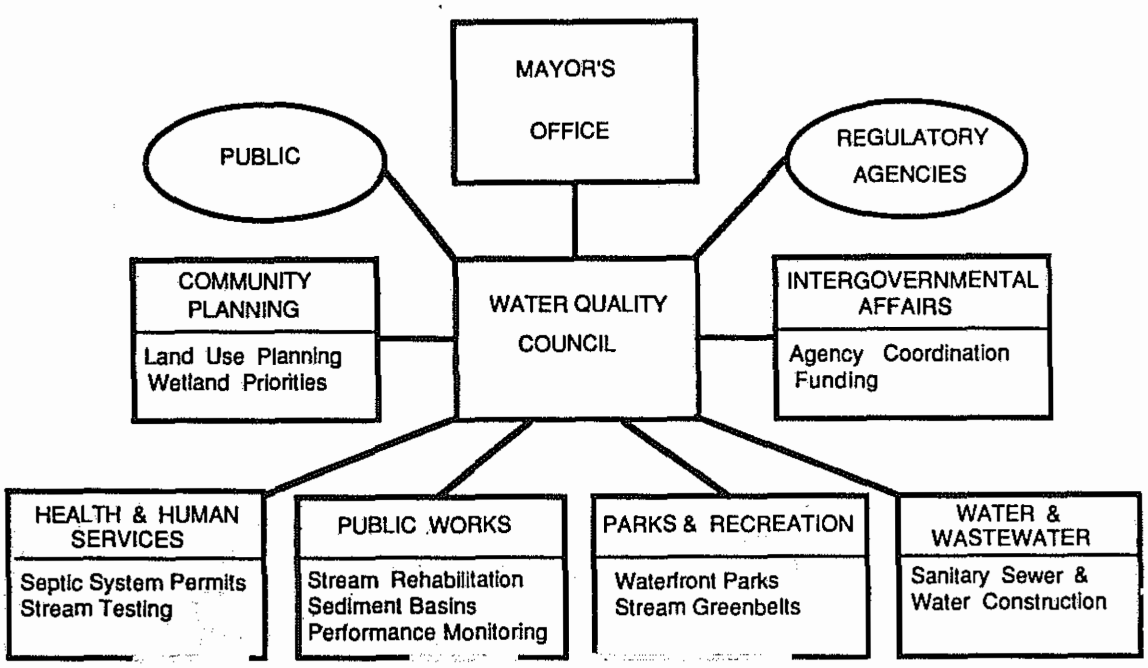

FIGURE 1. Water Quality Council

By July 1985, the Water Quality Council had established a set of goals and their Water Quality Work Plan (Municipality, 1985). The work plan incorporated ideas and aspirations. It enunciated principles and formulated policy issues as guides to goals and end points. The plan's simple and direct approach became a hallmark of subsequent individual creek action plans endorsed by the council.

PROJECT FUNDING AND PRIORITIES

Money was required in order to advance major aspects of the plan. Mayor Knowles, seeing an opportunity to consolidate public opinion in support of water quality, crafted a unique financing strategy. Rather than funding water quality projects from traditional public works bond issues, a special bond proposal for water quality was added on the November 1985 ballot. The $10 million water quality bond passed by the largest margin of any bond proposal that year. At a time when government spending was beginning to be carefully scrutinized, the public came through to show their concern in a way that made a difference. In the 1986 election an additional $5.5 million was approved. The message was clear; everyone wanted improvement.

The Water Quality Council went to work identifying projects suitable for the bond funds. However, the project selection process became enmeshed in departmental competition for resources. The process was complicated by the fact that each department had its own priorities, without an easy way of measuring their priorities against those of other departments. In addition, the council had no internal funding or staff to manage programs in the usual sense. There was no "water czar" to dictate priorities, other than the mayor, and he astutely deferred the mechanics of solution to the council.

In January 1986, the department of Public Works, sensing a need to rationally prioritize its own substantial list of projects for council review, developed a ranking system. Compiling a list of all known water quality problems along Anchorage's streams, Public Works developed a simple set of criteria and a scoring system for ranking its projects. The criteria chosen reflected key community objectives to be met for a water quality program that would provide long-term benefits. Four goals were essential to the success of the program: pollution reduction, habitat enhancement, community education, and governmental cooperation. The relationship of the first two goals to solving the water quality problem was obvious, but the department realized that without the last two goals progress would only be short term.

The selection criteria and ranking methodology was presented to the council in a report, Water Quality Improvement Action Plan for the Little Campbell Creek Basin (Municipality, 1986). The council endorsed the approach for Public Works' water quality projects and requested the department rank all potential water quality projects under consideration by the council. Public Works worked with the other council member departments to gain concensus on the basis for criteria. Once this was achieved, project selection became relatively straightforward for the council.

PROJECTS

With the money available and the selection process in place, getting the improvements underway ensued. Sedimentation basins, oil/grease separators for existing storm drain outfalls into creeks, and stream restoration projects were the most visible signs of progress. The Parks and Recreation Department coordinated several of their property acquisitions with Public Works. This effort enhanced areas surrounding sedimentation basins along greenbelts to provide a park-like atmosphere. Some of the projects also provided land for trail connections. One particular sedimentation basin project in the Northwood Park area is becoming a model park plan, providing an island for water fowl and song bird observation, as well as water cleansing features.

Thirty-two projects (Table 1), totaling $15.5 million, were identified. Of these, five sedimentation basins, seven stream restorations, and four oil and grease separators were put "on the streets" for design and construction. Nine greenbelt/parkland acquisitions totaling $3 million were funded by water quality bonds. In addition to the highly visible improvements, the Health and Human Services Department established a 3:1 government-private matching grant program to assist property owners of riparian land in restoration of streams and lakes. Additionally, ground and surface water monitoring stations along streams together with nearly 100 shallow ground water testing wells were established. A study of septic system impact on water quality in high risk subdivisions was initiated. The existing water laboratory at the Point Woronzoff treatment plant received funding for improvements to provide for the testing needs of the water quality program.

REGULATORY/INSTITUTIONAL CHANGES

Beyond the project phase, and with strong incentives, came laws, ordinances, and policies. The dedication of stream maintenance and protection ordinances granted the power to protect and maintain the municipality's waterways. In May 1985, municipal code was changed to prohibit building structures within 25 feet of a stream. An ordinance prohibiting the operation of motorized vehicles on certain bodies of water was enacted in June 1986.

Existing ordinances concerning sewer service were enhanced to include water quality concerns. In May 1986, a comprehensive wastewater ordinance was adopted. Among other things, it prohibited future subdivisions from having on-lot septic systems unless each lot was at least

TABLE 1. Water Quality Bond Projects

DEPARTMENT	PROJECT TITLE
Community Planning	Connors Bog Acquisition Delong Lake Acquisition
Anchorage Water and Wastewater Utility	Point Woronzof Laboratory Fish Creek Trunk
Solid Waste Services	Hazardous Waste Collection Center
Parks and Recreation	Little Campbell Creek Acquisition Miscellaneous Greenbelt Acquisition Rabbit Creek Acquisition Chester Creek Acquisition Fish Creek Acquisition
Health and Human Services	Ground Water Stations Test Wells Public/Private Matching Program Little Campbell Creek Monitoring Municipal Wide Monitoring Septic System Impact Studies
Public Works	Sedimentation Basin BI1 Sedimentation Basin BE2 Sedimentation Basin E2-2 Northwood Park/Fish Creek Sedimentation Basin Campbell Creek @ Minnesota Drive Sedimentation Basin Essex Square Acquisition Sedimentation Basin Chester Creek Oil/Grease Separators (3) Clark's Way Oil/Grease Separator 84th/Abbott Loop School Stream Restoration Our Road/Little Campbell Creek Restoration Chester Creek Reconstruction Little Campbell Creek Hartzell/Lake Otis Restoration Little Campbell Creek @ E. 68th Ave. Restoration North Fork Little Campbell Creek/Old Seward Highway-New Seward Restoration King Tract Acquisition Westchester Lagoon Restoration

40,000 square feet in size and had suitable soils. Lobbying efforts at the state level by the Water Quality Council's vice chairman resulted in the inclusion of water quality projects being eligible for municipal-state 50/50 matching grant funds.

At a department level, Public Works initiated a review of policies of the divisions responsible for subdivision development and building construction. Areas of drainage authority and inspection responsibilities were clearly defined to eliminate confusion.

More emphasis was focused on drainage planning for proposed developments to insure that additional problems were not created. Requirements for a site drainage analysis are now being implemented that include natural drainage, project-drainage impacts, and water quality concerns.

Public Works also focused on construction methods. A major source of water-borne sediments was construction activities. An erosion control specification was incorporated into construction contract documents.

CONCLUSIONS

Some conclusions can be drawn from the relatively short period of time that the municipality has been endeavoring to improve and protect water quality.

- There had to be broad public desire/concensus in order to achieve the goals. Government alone could not accomplish its goals without the support and backing of individual citizens, organizations, and the public in general. The citizens endorsed water quality efforts by passing two sizeable water quality bond issues.

- Support from top political leaders was imperative. Without the mayor, assembly, and the governor, little would have been accomplished.

- Intra- and inter-governmental cooperation was essential.

- Water quality improvements could be achieved without reorganizing government, specifically without creating a water authority as such. Water quality became everybody's business.

- The task was to be bigger than anticipated. Cleaning urban streams and lakes proved to be a formidible task.

ACKNOWLEDGEMENT

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THE ROLE OF A CITIZEN GROUP IN ADVOCATING WATER QUALITY

by the Anchorage Waterways Council[1]

ABSTRACT

The Anchorage Waterways Council (AWC) has actively engaged in a program directed at educating the public and monitoring activities that could affect water quality within the Municipality of Anchorage (MOA). With Municipal funding, the AWC has undertaken a major stream cleanup project each spring, developed three public service announcements, and created a slide show. In addition to the educational and cleanup efforts, the AWC Issues Committee actively monitors current events. Activities undertaken by the group include assessing the enforcement of water quality programs within the Municipality, responding to Corps of Engineer's permits, critiquing the criteria for expending the water quality bond monies, proposing projects for inclusion in the expenditure of these monies, and responding to concerns raised by the public (eg. the fate of the paint used on lakes to mark cross-country ski trails).

INTRODUCTION

Achieving high standards of water quality in any community can be facilitated through the active participation of interested residents. The Anchorage Waterways Council (AWC) is an organization that was established by Anchorage residents for just such a purpose.

Every group undergoes agonizing moments as they are forming -- asking questions about and probing issues such as the purpose, scope, and organizational framework that should be used. By describing the final product of our deliberations, some of the successes achieved, and some of the pitfalls, we hope to aid others who might wish to promote local water quality through citizen advocacy.

BACKGROUND

The AWC first met in 1984 following the initial creek cleanup effort. Although cleanup efforts focus on creeks, other types of waterbodies and water quality issues were recognized as important by the original participants. When the AWC was officially organized in 1985, the scope of the charter was city-wide and water quality issues spanned all types of waterbodies -- rivers, lakes, streams, and wetlands.

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The AWC decided to focus on four goals: to educate the public on the importance of clean water and how individuals can enhance water quality; to provide technical advice on effective cleanup measures; to influence public policy concerning water quality; and to promote community service projects such as the Annual Spring Creek Cleanup.

ORGANIZATIONAL STRUCTURE

Membership in the AWC is open to all interested persons. The AWC applied for, and received, a non-profit status so that the $10.00 annual membership fee is tax-deductible. The membership is guided by a Board of Directors that can range in number from 13 to 17. The Board meets monthly. The four officers of the Board, a President, Vice-President, Secretary, and Treasurer, and one Board member on each standing committee comprise the Executive Committee. The Executive Committee can act on behalf of the Board in most cases. To date, this committee has not been used. Three additional standing committees were established -- the Organization Committee, the Issues Committee, and the Education Committee. These committees, which meet on a regularly scheduled basis, are actively involved in the projects that are sponsored by the AWC. Responsibilities for each committee and projects that they have undertaken are described in the following paragraphs.

Organization Committee

The functions of the Organization Committee include recruitment and maintenance of membership, fund raising, publishing a newsletter, and coordinating the Annual Spring Creek Cleanup.

Initially, Jim Stratton of the Alaska Conservation Foundation provided us with a wealth of knowledge on how to contact prospective members to develop a basic membership. This year, we plan to build on that experience and to contact new people identified through the creek cleanup.

We have conducted several fund raisers. During the 1987 Creek cleanup, a volunteer designed and sold long sleeved tee shirts with the spring cleanup logo. While few excess funds were raised, the effort managed to cover costs. This summer a photography contest was held which, again, was able to cover costs. Next year the photography contest should do better based on the experience we gained during this first attempt.

As you can see, there is no replacement for experience. Even the Annual Spring Creek Cleanup has improved each year, helped largely by an accumulation of wisdom. The one undertaking of the Organization Committee that was effective from the outset was the newsletter -- and that can be attributed primarily to Cathy Gleason and Laura Ogar, two Board members who also assumed responsibility for putting out the newsletter.

Issues Committee

The Issues Committee is chaired by the Vice-President of the AWC Board of Directors. This committee identifies and addresses the substantive issues concerning water quality and submits policy recommendations to the Board of the AWC for action and transmittal to the appropriate governmental entity.

Issues are identified by the AWC Board, Issues Committee members, or the general public. Members of the committee volunteer or are assigned issues generally according to their interest or expertise. The member will research the issue and prepare a draft briefing paper that identifies and analyzes major problems, recommends specific solutions, and notes areas for further analysis. Solutions focus on concrete short-term and long-term actions to be taken by the AWC and the responsible governmental entities. The committee as a whole then discusses the issue. After the committee agrees on revisions to the draft briefing paper, the paper is submitted to the AWC Board for adoption as a formal position or plan of action.

Areas of concern identified by the Issues Committee include:

1. Legal and regulatory framework for water pollution control;
2. Water quality monitoring;
3. Sewage pollution;
4. Other point sources of pollution;
5. Nonpoint sources of pollution;
6. Wetlands and lakes;
7. Land use and water pollution control;
8. Fish and wildlife management associated with waterways.

Over the past few years, the Issues Committee has addressed a number of issues -- many of which led to a positive result. The following examples provide an overview of the range of issues addressed.

Conners Bog. Letters were sent to the Municipality of Anchorage (MOA) and to the Heritage Land Bank encouraging the acquisition of the bog by the MOA and protection of the bog from destructive use of off-road vehicles within the bog. The MOA purchased the bog but off-road vehicle use continued due to lack of enforcement. Another letter was sent to the MOA requesting that the laws prohibiting off-road vehicles in the bog be enforced. The MOA has reinforced the decision to prohibit off-road vehicles in the bog; plans are in place to fence off the bog to restrict access by the off-road vehicles.

Water Quality Bond Expenditures. Bonds were approved by MOA voters in the fall of 1985 and 1986 for funding water quality projects. The AWC closely monitored the use of these bond monies and helped to identify the projects that were selected for funding through the 1986 bond.

Water Quality Enforcement. The Issues Committee developed an analysis of the water quality enforcement program of the MOA and submitted the analysis to the Mayor. The analysis included the identification of six specific problems and provided recommendations to resolve the problems. The response from the Mayor was positive; results will be evaluated at a later date.

COE Wetlands Fill Permit Applications. Comments have been submitted on several applications for placement of fill in wetlands. Included have been a residential project in Klatt Bog, the Ship Creek Landing waterfront development project, and a shopping mall in the wetlands of Furrow Creek.

Legislative Bills. The Issues Committee has provided comment on several bill proposed in the State Legislature that related to water quality issues.

Education Committee

The Education Committee has the overall charge of promoting the purposes of the AWC. Approaches identified include;

1. Education of the public;
2. Curriculum development in grades K through 12;
3. Implementation of programs for post secondary and continuing education;
4. Informing and educating elected officials;
5. Informing and educating government personnel;
6. Informing and educating the media;
7. Sponsorship of events such as public meetings, conferences, symposiums, and presentations that deal with issues of water quality.

Several of these approaches have been used over the past three years. General education of the public has been fostered through three public service announcements developed by the AWC with funding from the Municipality. MOA funding also enabled the AWC to develop a slide show that has been used in the school district and in various public education forums, such as fishermen's groups and service organizations. Additional funding from the Alaska Conservation Foundation allowed for the purchase of the slide projectors needed to present the slide show.

A symposium on ground water issues, including design and maintenance of septic fields was presented. This was funded with donated time.

In 1987, the Education Committee focused on short radio spots to point out to listeners their roles in achieving and maintaining good water quality. The Committee also coordinated between the Anchorage School District and the Department of Public Works (DPW) to promote the use of a water quality educational program developed by DPW to be integrated into the school curriculum. The portion of the DPW program that is directed to older students uses the slide show developed previously by the AWC.

CONCLUSION

A concerned and active citizen's group can participate in the public forums and influence final decisions. Common pitfalls that befall such a group are not a reflection on the topic at hand -- water quality, but rather common to any citizen group that forms to accomplish a specific agenda.

One pitfall is the potential for an unreceptive audience. We have been fortunate in Anchorage that our views and opinions have been highly regarded. There are two apparent reasons for this success. First, the MOA administration has been receptive to our opinions, and second, we have focused only on issues where we had the interest and expertise to offer viable solutions after we had identified and analyzed the problem.

Another pitfall would be attempting to accomplish too much with too few people. The separation of the research tasks from the formal Board activities helps to distribute the work load. The standing committees for the AWC are designed to provide the needed backup to the AWC Board members. However, two of the three committees are comprised primarily of the Board members, with few general members participating.

The AWC is still a young organization, but the results have been rewarding. The successes of the past four years provides the AWC with the confidence that it can help to improve the quality of waterways in Anchorage. We would be pleased to assist anyone attempting to form a citizen's advocacy group and welcome those who would like to participate in the Anchorage Waterways Council.

MEDIATING WATER QUALITY
TURNING A DITCH BACK INTO A CREEK, THE ANCHORAGE EXPERIENCE

by Thomas R. Bacon[1] and Marideth J. Sandler, AICP[2]

ABSTRACT

The Little Campbell Creek Stream Rehabilitation Project is the Municipality of Anchorage's first major undertaking to improve the quality of its urban streams. The section of Little Campbell Creek was chosen because of its history of icing and subsequent-overflow, its proximity to Abbott Loop Elementary School, and the need for landscaping and habitat improvements along its channel. Working closely with a citizen committee appointed by the Mayor, the project team consisting of the Department of Public Works and Ott Water Engineers, Inc., completed a hydrologic analysis of the stream; proposed six design alternatives; met with the public, affected landowners, other Municipal Departments, and federal and state regulatory agencies; and facilitated committee decision making. The end product of the mediation efforts was an effective solution which resulted in nine tenants willingly moving from their homes so that the creek could be rehabilitated.

INTRODUCTION

The Little Campbell Creek Stream Rehabilitation Project was the first construction project to focus the Municipality of Anchorage's efforts to reverse the pollution of area streams. For this project the mediation effort was planned to address differences before they produced project conflicts. This effort required:

- the development of consensus and financial partnership between Municipal agencies,
- the early involvement of regulatory agencies,
- the participation of the neighborhood near the stream section,
- the cooperation of the Anchorage School District, and
- project team mediation of the interests of all involved parties.

Through this process the Municipality produced a stream design for a section of Little Campbell Creek that met community and technical goals, created an innovative educational program for elementary schools, and involved the neighborhood in the physical revegetation efforts.

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BACKGROUND

Up until the 1950's, Anchorage's streams meandered naturally through rural forested areas. Since then major sections of streams have been moved out of their natural alignments to provide space for development. The result has been:

- the loss of salmon spawning areas,
- increases in erosion and water pollution,
- increases in flooding and icing problems, and
- a loss of esthetic values.

As development turned streams into urban ditches, the community and affected government agencies remained fragmented. Many agencies concentrated on their own priorities instead of sharing expertise and resources for common solutions.

Early in 1985, testing by the State of Alaska Department of Environmental Conservation indicated that pollutants in the city's streams exceeded state water quality standards. Responding to the news, Anchorage Mayor Tony Knowles established the Water Quality Council to provide coordination for a Municipal water quality program. The Council, composed of all Municipal departments with water resource responsibilities, began meeting on a regular basis

Initially the Council lacked direction. Differences of opinion prevented a quick establishment of Municipal water quality goals, but the Mayor insisted that solutions be found for Anchorage's water quality problems. As discussion continued into the summer of 1985, participants agreed that, in addition to decreasing the existing values of chemical and biologic pollutants, improvement of esthetic and fish habitat values had to occur in area streams.

The elements of the water quality program became apparent:

- The Municipality needed to acquire land to preserve wetlands and to buffer streams and lakes from urban growth.
- Water quality projects needed to include stream reconstruction and the construction of oil and grease separators and sediment basins.
- Collection of better water quality data was necessary to provide a basis for project design and evaluation.

Because the proposed projects greatly exceeded available funds a simple criteria system, developed by the Department of Pubic Works, was used to prioritize the project list. Recognizing that water quality problems included both technical and social considerations, the chosen criteria reflected the four water quality program goals of pollution reduction, habitat enhancement, community education and governmental coordination and cooperation.

In summary, through a goal setting and project evaluation process that took almost one year, the Water Quality Council:

- opened lines of communication between affected agencies,
- identified the types of required projects,
- obtained funding from the voters, and
- approved a prioritized list of projects.

THE PROJECT

One of the projects near the top of the list was the Little Campbell Creek stream rehabilitation project near Abbott Loop Elementary School. (See Figure 1) This stream section of approximately 1,000 feet, located east of Lake Otis Road, represented an ideal test of what could be done to rehabilitate an urban stream. The flat bottom ditch section was confined on one side by a trailer court and on the other side by the school playground. There was a lack of riparian vegetation and the bottom had been graded to increase hydraulic efficiency thereby eliminating all stream bottom habitat. Public Works allocated $180,000 to the project and requested proposals for design services from private engineering firms.

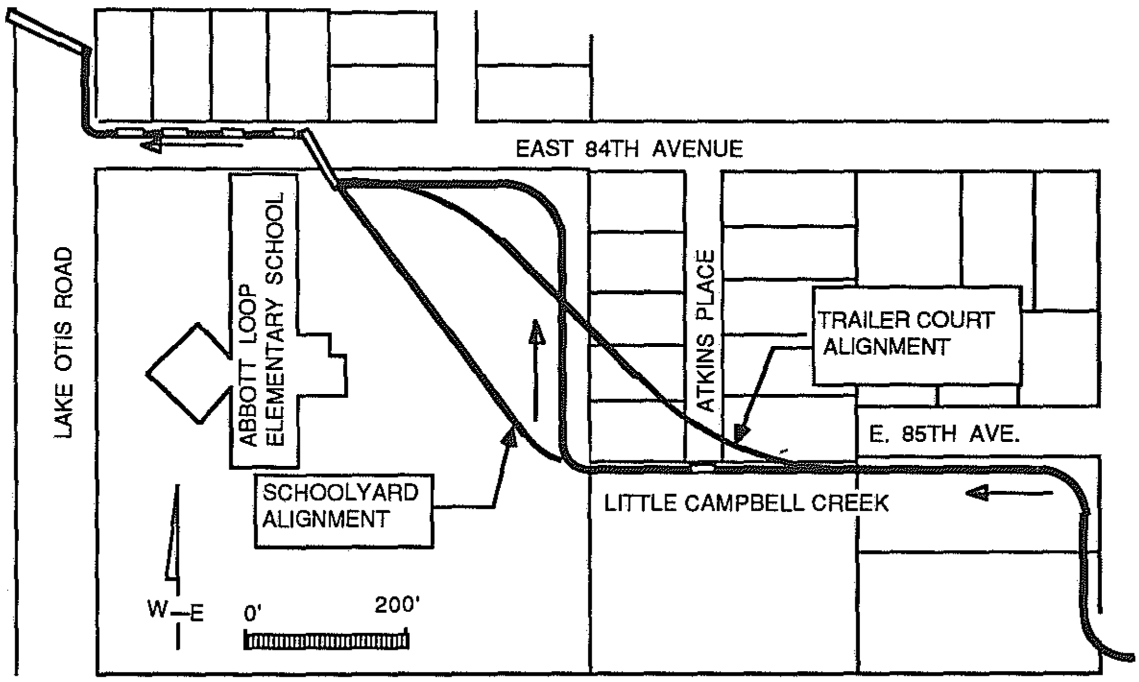

FIGURE 1. Little Campbell Creek Near Abbott Loop School

Before the design proposals could be reviewed, icing filled the existing channel and the stream overflow flooded the school playground in February of 1986. High fecal coliform counts indicated a possible health hazard and the story with pictures of the flooding appeared in local newspapers.

Following the flooding, the local PTA met with school administrators and representatives of the Municipal Departments of Health & Human Services and Public Works. The meeting was heavily attended. Several participants suggested piping the creek underground to solve the flooding problem. Many people questioned the ability of the local government to provide an acceptable solution.

A week later the Mayor visited the school site and pledged to cooperate with the Anchorage School District to find a solution for the flooding problem. After reviewing the icing problem , Public Works increased the project budget to $500,000 and the Department of Parks and Recreation agreed to provide an additional $200,000 in land acquisition funds if purchased areas could be used for recreational purposes.

ORGANIZING THE PROJECT

Public Works selected Ott Water Engineers, Inc., to provide design services for the project. The project scope emphasized two factors. First, little time was available to develop a solution. Most important, the neighborhood had a stated a lack of confidence in governmental solutions for their problem and a major effort was required to convince them of the merits of any proposal.

For the Little Campbell Creek project Public Works and Ott Water Engineers decided to form a unified project team. The standard review and comment process imposed obstacles to a quick exchange of ideas and the time required for reviews conflicted with the neighborhood demand for a fast solution to their flooding problems.

Specialists from the Ott Water Engineers staff provided expertise in the areas of civil engineering, hydrology, fisheries biology, permitting and public participation techniques. The Municipal project manager was responsible for insuring that the design remained on schedule and within the project budget and that technical proposals met Municipal goals and policies. Communication between Public Works and Ott Water Engineers was simplified and a structure was established to quickly bring necessary expertise together to discuss and resolve problems as they occurred.

Recognizing that the success of the project depended on public and interagency support, the project team initiated an extensive public involvement program. The involvement program included formation of a citizen review committee, a program of neighborhood participation and education, and early meetings with federal and state review agencies. All aspects of the public involvement program were integral to the design decisions for the Little Campbell Creek project.

THE CITIZEN REVIEW COMMITTEE

At the beginning of the project the Mayor appointed a five-member citizen review committee to oversee the design effort. The committee consisted of:

- two neighborhood members selected by the Abbott Loop Elementary School PTA,
- one member selected by the Abbott Loop Community Council,
- a member selected by the Anchorage School District administration, and
- a member selected by the Anchorage Waterways Council, an advocacy group for water quality issues.

From its formation the committee acted as a major project element. The committee met once a week to review and discuss information prepared by the project team. Information included a hydrologic analysis and six conceptual designs for improving the stream. Between meetings the members of the committee met with their neighbors and local organizations to share project information.

In the first committee meeting the project team explained the proposed meeting schedule and clearly defined the citizen review committee's role and responsibilities:

- The committee had the full responsibility to select the project design elements;
- Selected design elements could not cost more than the authorized funding;
- Committee decisions had to keep pace with the design schedule;
- The design had to meet permit agency requirements; and
- The final design had to reduce flooding and improve stream habitat values.

Turning the decision responsibility over to representatives of the neighborhood helped mitigate the controversy of a government imposed solution. Also, the local residents knew many details of the stream problems and provided important information with respect to the project priorities. The project team depended on providing an organized process of committee decision-making to minimize the risk of poor technical decisions by the participants..

The citizen committee members needed education about essential stream rehabilitation issues. Their understanding of the pertinent design objectives, technical terms, and concepts required translation into the language of a lay audience. Photographs, aerial photographs and graphics were used to facilitate discussions. All material was reviewed for clarity and completeness, and presentations were also reviewed to insure that the project team stated facts objectively and left decisions to the committee members.

The committee quickly identified their priority problem areas and set goals for the project. Based on the committee priorities and project budget limitations, the team presented four alternatives for consideration. Three of the alternatives, channel modifications along the existing stream alignment created habitat improvements, but they were only partially successful in solving the flooding problems. The fourth alternative, a stream realignment through the middle of the schoolyard, was the best technical solution, but this solution conflicted with the children's use of the elementary school site.

The committee looked for another alternative and suggested two additional proposals. Habitat improvements could be made along the existing alignment with a winter overflow pipe under the schoolyard or the stream could be realigned through the adjacent trailer court. Both suggestions, however, exceeded the project funds.

Two more meetings with the citizen committee took place before a decision was made for the project. During that time the project team met with all of the residents in the trailer court and with Parks and Recreation. The residents of the trailer court indicated they would be willing to move for the project if they were offered fair value for their property. Convinced that the project provided a substantial neighborhood amenity supported by the local residents, Parks and Recreation agreed to provide additional land acquisition funds. With the additional funds the stream alignment through the trailer court was a viable alternative.

The citizen committee approved the trailer court alignment with the provision that trailer owners could not be forced to sell their property and renters would not be forced to move. In their approval the committee recognized that opposition by any one property owner or renter could stop the project. They also recognized that the time required for negotiations precluded project construction in 1986. The committee members agreed to go back to their organizations and explain the need for the project delay.

The citizen committee was a successful mediation effort for the project. Important factors are:

- The project team structured the meetings. The purpose of each meeting was clearly defined and decisions were made only when the necessary information had been presented to the committee.
- The committee made their own choices between technical and social considerations for the neighborhood. The final solution was not viewed as government imposed.
- The committee acknowledged the risk that their preferred alternative might not be possible and took the responsibility for the project delay.
- Committee advocacy kept the project visible and was largely responsible for the additional funding required to provide an acceptable solution.

NEIGHBORHOOD PARTICIPATION PROGRAM

Public involvement also included participation by the neighborhood residents. Concurrent with a predesign stream inventory by the project team, a letter was distributed to all property owners in the project area explaining the general purpose of the project and informing them that there would be design personnel and surveyors working along the creek. At the same time a member of the project team began knocking on the doors of the resident's homes who lived adjacent to the stream to discuss their concerns.

The project team continued the neighborhood participation program by holding a public meeting for the people who lived in the project area. The project was explained and the resident's concerns were noted.

After the citizen review committee reviewed the original four alternatives, a second public meeting was held. After general questions were aswered, the participants were divided into four smaller working groups to review and discuss the project. A final meeting was held prior to the notice to proceed for construction to show the local community the final design.

Another neighborhood outreach effort involved the development of an educational program for the 700 children attending Abbott Loop Elementary School. Using a story about stream resident, Sally Salmon, the instruction informed the students about the differences between a stream which is a good environment for fish and the present state of Little Campbell Creek. The program also emphasized the children's roles in not destroying vegetation and in keeping the creek banks free of litter.

As a follow-up to the educational program the Abbott Loop Parent Teacher Association agreed to hold a neighborhood planting day. A specific section adjacent to the realigned creek has been set aside to allow for the children and their parents to participate by planting trees and bushes for the project.

The participation program for the area residents was important not only to mitigate the idea of a government imposed project, but the process integrated neighborhood priorities into the project. The neighborhood children who have the greatest contact with the creek were directly involved with the process. The participation program developed important support to maintain project benefits after construction.

AGENCY MEDIATION

Agency mediation required obtaining input and cooperation from a number of permit and review agencies (Table 1). The project team identified permitting agency values and requirements early in the project so necessary design details could be incorporated.

TABLE 1. Project Permitting Requirements

Agencies	Permits
Federal Emergency Management Agency	Flood Hazard Permit
Corps of Engineers	Section 404 Permit
State Division of Governmental Coordination Consistency Determination	Coastal Zone Management
State Department of Fish & Game	Title 16 Habitat Permit
Municipal Urban Design Commission	Landscaping Review

Coordination with the regulatory agencies began with a meeting to identify their concerns and to gain a consensus on their preferred stream design concepts. The meeting was scheduled to allow the project team to provide information back to the citizen review committee for their decision making process.

The agency representatives provided invaluable input during the meeting. Their comments included the following considerations:

- Stream reconstruction must include fish habitat enhancement.
- Land acquisition should include buffer areas along the creek.
- Erosion control was necessary during construction.
- Quality assurance was required to insure facilities were constructed as designed.
- Educational information should be provided to the Abbott Loop Elementary School children.
- Information required to facilitate permit applications was identified.

During the design process the project team continued discussion with agencies on an individual basis to clarify the acceptability of design concepts. Prior to submitting permit applications the project team held a second agency meeting to insure that the design concepts and permit details were acceptable.

To provide coordination with municipal agencies a project presentation was made to the Water Quality Council. Individual meetings were also held with the Department of Parks and Recreation and with the Anchorage School District throughout the design process.

Benefits of he agency mediation process include:

- Information was supplied to the agencies early in the process.
- Necessary project design elements were identified early in the project.

• Agency input was obtained before design funds were expended.
• Permit acquisition was expedited.
• A forum was provided for discussion and resolution of agency differences.

MEDIATION SUMMARY

The project mediation effort provided a nonconfrontational environment in which the necessary elements were brought together for a successful design. These elements included use of a citizen review committee, extensive neighborhood participation, and direct agency mediation. The process allowed incorporation of social concerns into the design process concurrent with providing solutions to the identified technical problems. Perhaps more important than the final selection of the project design elements, the mediation effort opened communication between pertinent agencies and proved that the Municipality could work with the neighborhood residents on an equal footing to solve problems of mutual concern.

In summary the project offers several insights:
• Extensive public involvement of adjacent property owners and neighborhood residents resulted in open acceptance of project goals and in easier and less controversial right-of-way acquisition.
• Because of the neighborhood's knowledge of its own needs was incorporated into the solution, the finished project succeeded more than the project planners originally had envisioned.
• Inclusion of input from key regulatory agencies early in the process clearly benefited the project. Incorporating their suggestions and ideas from the beginning helped define the possible alternatives and saved design dollars.
• Solution-making effectively involved the efforts of more than one administrative department. Originally the concern primarily of the Department of Public Works, this project also accomplished the goals and utilized the resources of the Department of Parks and Recreation. The key to this accomplishment was that project management was in the hands of a project team who saw interdepartmental cooperation and resource pooling as vital ingredients to project success.
• The project team stayed flexible. From the beginning of the Anchorage water quality program there have been many times where an inflexible stance would have damaged, perhaps destroyed, real opportunity for urban stream improvements. This project is an example of how a flexible approach can result in a creative multipurpose solution.
• Finally, restoration of this urban stream was more than a hydrologic analysis and a hydraulic design problem. The stream's human neighbors had strong emotional ties to it. Given the opportunity, these neighbors became actively concerned with the stream's health and visual quality and helped develop solutions that accomplished more than just meeting the stream's hydraulic needs.

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EVALUATION OF GROUNDWATER QUALITY MANAGEMENT IN ALASKA

William S. Ashton [1]

ABSTRACT

Recent cases of groundwater contamination in Alaska have prompted an increased concern for the protection of groundwater quality. Prior to developing new programs to address groundwater protection, government agencies need to review how well existing programs protect groundwater. Strengths of existing groundwater quality management in Alaska include: broad statutory authority for the Department of Environmental Conservation (DEC) to regulate sources of contamination; the majority of source control programs within one agency (DEC); water quality standards which include groundwater; and a state-funded hazardous substance and oil spill response fund. Recommended areas for improvement in administration of existing regulations include updating existing permit application and review procedures to specifically address impact on groundwater quality and improving coordination among the various source control programs within agencies and between agencies and local governments. Areas in which regulations should be developed or expanded include: prevention oriented regulations for petroleum storage tanks; water well and monitoring well design and construction standards; and development of regulations to manage water use in coastal areas to limit saltwater intrusion.

INTRODUCTION

Groundwater is a valuable resource to be maintained at a high quality for present and future use. It is utilized by 2,045 of 2,400 (85%) public water systems in Alaska (Richard Farnell, DEC, oral commun.,1987). These systems provide residential water to 295,000 people, approximately 55 percent of the state's population. No accurate count exists of the number of private water wells in the state. A rough estimate is 30,000 wells serving an estimated 90,000 people. For the majority of Alaskans utilizing groundwater, it is abundant and of high quality. However, there are areas of the state such as the Copper River valley and portions of the Fairbanks North Star Borough where groundwater quality is poor due to natural conditions (Emery, Jones, and Glass, 1985; Hopkins and Maxwell, 1985).

Concern in Alaska about groundwater contamination and the potential contamination of underground drinking water sources is increasing. Alaska is generally considered rural and pristine, however, petroleum products have

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contaminated village drinking water sources, as well as, urban drinking water sources. Besides petroleum storage facilities, potential sources of groundwater contamination include on-lot wastewater disposal systems; underground injection of industrial wastes, oil and gas exploration and development wastes, drainage and urban runoff, and sewage wastes; solid waste landfills; water use rates which cause saltwater intrusion; and improper handling of hazardous substances. Each of these has caused groundwater contamination in Alaska (Munter and Maynard, 1987).

The purpose of this evaluation is to describe the primary federal, state, and local government authorities and regulations for groundwater quality protection. General descriptions of the primary laws and regulations which address groundwater protection follow. For specific requirements refer to the laws and regulations. Federal and state authorities and programs which provide supporting roles in data collection are not described here.

FEDERAL AUTHORITIES

The federal government oversees a broad range of groundwater quality related programs through the Environmental Protection Agency (EPA), Department of Interior, Department of Agriculture and other federal agencies. These programs provide research, technical assistance, funding, and regulation for groundwater problems. The U. S. Environmental Protection Agency (EPA) is directed by Congress to protect the nation's land, air, and water. Several environmental laws direct EPA with respect to regulating activities which may contaminate groundwater. At this time there is no law similar to the Clean Air Act or Clean Water Act which works to unify legislative intent for groundwater protection.

Of the national environmental protection laws, seven provide for some protection of the nation's groundwater. They are the Clean Water Act (CWA); the Safe Drinking Water Act (SDWA); Resource Conservation and Recovery Act (RCRA); Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, more commonly known as Superfund); Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); Toxic Substances Control Act (TSCA); and Surface Mining Control and Reclamation Act (SMCRA). These laws provide the basis for current federal groundwater protection regulations and minimum requirements for most of Alaska's regulations. The first four laws have been significantly amended in the past two years to add sections on groundwater monitoring and protection. For more detailed descriptions of these laws refer to Henderson, Trauberman and Gallagher (1984) or Gordon (1984).

Clean Water Act

The primary emphasis of the Clean Water Act is protection of surface waters. This is accomplished through grant programs for construction of sewage treatment works, requiring facilities where petroleum products are stored to prepare Spill Prevention and Countermeasure Plans for preventing or responding to inadvertent discharges of oil, and regulating discharges into surface waters. The CWA directs states to develop water quality standards for all waters and to classify these waters. Many states did not include groundwater in these standards. EPA was directed to set minimum criteria states must meet. The main provisions for groundwater protection are sections 106 and 208: planning and funding for developing water quality management plans. Amendments to the Act in 1987 added provisions addressing nonpoint source pollution and toxic substances.

Safe Drinking Water Act

The primary emphasis of the Safe Drinking Water Act is to ensure that drinking water from public water systems is safe for human consumption. Public water systems defined by the act are those systems serving at least 25 people or having at least 15 service connections. The SDWA provides for adoption and enforcement of a set of national quality standards (maximum contaminant levels) for contaminants affecting health. These standards are "end of the pipe" standards and, under the SDWA, do not apply to the source of drinking water.

Additional sections of the SDWA address underground injection of wastes, protection of sole source aquifers, and development of wellhead protection areas around public water supply wells. The underground injection provisions provide for regulation of wells used for injection of contaminated water or other hazardous wastes that pose a potential threat to underground supplies of drinking water. EPA has interpreted this to include dry wells, septic systems for businesses and residential facilities that are duplexes and larger.

Local or state agencies can petition EPA for a sole source designation of an aquifer. This means federal funds are prohibited for projects which may contaminate the designated underground water supplies. Also, injection wells can be prohibited in a sole source aquifer area. Wellhead Protection Areas (WHPAs) refer to the surface and subsurface area surrounding a well or wellfield that supplies a public water system through which contaminants are likely to pass and eventually reach the well or wellfield. Each state may define WHPAs and how their source control programs would be modified to incorporate them.

Resource Conservation and Recovery Act

The Resource Conservation and Recovery Act addresses the regulation of hazardous wastes, solid wastes, and underground storage tanks. RCRA regulates the handling of hazardous wastes from point of generation to point of disposal. Specifically, RCRA establishes guidelines for dealing with the generation, transportation, treatment, storage, and disposal of hazardous wastes. The solid waste portion of RCRA addresses the management of non-hazardous wastes in an environmentally sound manner.

Underground storage tanks covered by RCRA are any tank or combination of tanks (including underground pipe connections) that contain a regulated substance and in which 10 percent or more of the volume is under the ground surface. Major exceptions to this definition are farm or residential tanks of 1,100 gallons or less used for storing motor fuel for noncommercial purposes, heating oil tanks on the premises where the fuel is used, and septic tanks. States may apply for funding from EPA to use for investigation and cleanup of spills from underground storage tanks.

Comprehensive Environmental Response, Compensation, and Liability Act

While RCRA primarily regulates present and future waste management, the Comprehensive Environmental Response, Compensation, and Liability Act, is designed to provide funds for cleaning up hazardous substances, pollutants, or combined releases, typically from abandoned disposal sites.

Three features of CERCLA are especially relevant for groundwater protection. The Hazardous Substances Response Fund, "Superfund", was established to provide financing for government cleanup of actual or threatened releases of substances which may harm public health or the environment. The fund is supported primarily by taxes on petroleum products and chemical feedstocks. Second, CERCLA includes provisions to hold polluters liable for government cleanup costs, and to force polluters to contain and clean up contamination at their own expense. Finally, the Act establishes a hazardous substance notification program.

Federal Insecticide, Fungicide, and Rodenticide Act

The Federal Insecticide, Fungicide, and Rodenticide Act establishes the registration of pesticides. Under the registration program pesticides are tested for their potential leaching characteristics. Manufacturers of pesticides suspected of contaminating groundwater may have to monitor experimental or actual usage to determine actual effect. Pesticides can be banned from use in sensitive areas where monitoring shows that contamination has occurred.

Toxic Substance Control Act

The Toxic Substance Control Act regulates the manufacturing, processing, use, and disposal of toxic chemicals. Chemicals with potential to contaminate groundwater and create an "unreasonable risk" to human health or the environment may be subject to the following controls: 1) limit the use of the chemical, 2) require warning labels, 3) mandate that users take pollution control measures, and 4) require the development of special disposal plans.

Surface Mining Control and Reclamation Act

The Surface Mining Control and Reclamation Act regulates surface coal mining and its potential effects on water quality, both surface water and groundwater. National environmental performance standards were developed for surface and deep mining. These performance standards include many groundwater provisions. Mine operators must replace any water supply systems using groundwater which is affected by mining, carry out extensive groundwater studies before and during mining, and monitor groundwater quality in the area.

STATE AUTHORITIES

Alaska Statutes pertaining to groundwater quality fall into the following categories: protection of ambient conditions, protection of public health, sampling of ambient conditions, authority to regulate development which may affect groundwater quality, response to oil spills, appropriation of water, and land use planning as it affects groundwater recharge areas. In most cases, Alaska Statutes provide state agencies and local government greater latitude in implementing groundwater protection measures than federal laws or regulation.

Several state agencies and commissions have statutory responsibilities related to the protection of groundwater. The Department of Environmental Conservation is concerned primarily with protection of public health and the environment. The Department of Natural Resources (DNR) is concerned primarily with appropriation of waters of the state; collecting, recording, evaluating, and distributing data on water quality and quality within the state; regulation of coal and other types of mining; and state land use planning on those lands retained in state ownership. The Alaska Oil and Gas Conservation Commission (AOGCC) regulates the exploration, development, abandonment of oil and gas wells, and underground injection of non-hazardous materials associated with oil and gas wells.

State authorities are described by their program or function since state regulations are derived from a set of statutes, rather than individual laws.

Water Quality Standards

Water quality standards set the degree of degradation that may not be exceeded in a water body as a result of human activities. Water which under natural conditions, has a higher quality than the criteria set out in the water quality standards must be kept at the existing quality unless otherwise permitted (Alaska Administrative Code 18 AAC 70.010 (b) and (c)). The state water quality criteria must be at least as stringent as federal criteria.

Waters of the state are divided into two main use classes--fresh waters and marine waters. Within these classes, there are three major protected uses: water supply; water recreation; and growth and propagation of fish, shellfish, and other aquatic life, and wildlife. Groundwater is included in the classification of state waters and is protected for use classes fresh water water supply and marine water industrial water supply. It is important that water quality standards include groundwater so that permitting can use the standards as limits in permit requirements and so that there is regulatory water quality standards to use in remediation efforts.

Wastewater Disposal

Wastewater disposal applies to domestic and nondomestic wastewater discharge into or onto waters or lands in the state. Domestic wastewater includes waterborne sewage or graywater derived mainly from dwellings, commercial buildings, institutions, or similar structures. Nondomestic wastewater includes liquid or water-carried wastes resulting from a manufacturing, food processing, or production enterprise; industrial establishment; development of natural resources; or construction of a manufacturing, production, or industrial facility; or other wastes which are waterborne or in a liquid state (18 AAC 72.990 (16) and (29)).

With the exception of domestic wastewater disposal for a single family residence, all persons who dispose of domestic or nondomestic wastewater must apply for a permit. The potential impact on groundwater quality is evaluated during permit review and conditions may be stipulated in the permit to limit the impact on groundwater quality.

Solid Waste Management

Solid waste management addresses the handling, storage, and placement of drilling wastes, garbage, refuse, sludge, and other discarded material (18 AAC 60). Groundwater-related aspects of the regulations include evaluating the potential for leachate generation and water pollution based on site conditions described in the permit application. There are requirements for installation of monitoring wells and analysis of groundwater quality prior to depositing waste in a facility. Permit conditions specify water quality parameters to sample for, sampling intervals, and sampling requirements. Drilling muds associated with oil exploration and development are regulated as a solid waste.

Public Drinking Water

Public drinking water systems are divided into three classes. Class A includes systems which is expected to serve at least 25 residents, Class B includes systems which is expected to serve at least 25 people per day for at least 60 days a year and is not a Class A system, and Class C includes all water systems which are not Class A or B and are not a single family residence (18 AAC 80). The Safe Drinking Water Act sets the minimum requirements for the regulation of Class A and B systems. The regulations require minimum separation distances between water supply wells and potential sources of contamination. State regulations set maximum contaminant concentrations allowed in the water system. These concentrations must be at least as stringent as federal standards.

Oil Pollution Control

These regulations govern spill response, spill contingency planning, and financial responsibility (18 AAC 20 and 18 AAC 75). Aspects related to groundwater include consideration of the potential for groundwater pollution in granting surface oiling permits; reporting, cleanup, and disposal requirements for oil spills on to land or waters of the state; requirements for spill mitigation plans and spill detection systems at oil storage facilities with capacity of 10,000 barrels or greater; and setting out civil penalties for persons who spill oil onto land or into waters of the state, or who fail to report a spill.

A state "superfund" was established in 1986 for cleanup, containment, site investigation, monitoring, and evaluation of oil and hazardous substance releases or threatened releases. The fund is supported by legislative appropriations, and is used for responses in which the responsible party is not known or is not cooperative in starting cleanup actions. DEC pursues legal action to recover its costs for cleanup and damages to state resources.

Hazardous Waste Management

State hazardous waste management regulations adopt the federal regulations (18 AAC 62). These regulations address the generation, transport, storage, and disposal of hazardous wastes. The groundwater sections of the regulations define groundwater monitoring requirements and procedures for corrective action monitoring.

Pesticides

Pesticide regulations address the use, transport, sale, application, and operator training and certification procedures for proper application (18 AAC 90). Groundwater-related provisions of the regulations include DEC review of permit applications to apply pesticides to waters of the state, by aircraft, or for a public pesticide project. Pesticide permits can be denied if the minimum planned precautions are inadequate to protect the public health or safety, or the environment.

Water Use Allocation

All waters of the state are reserved to the people for common use and are subject to the rule of "priority of appropriation shall give prior right" (11 AAC 93). Water use is regulated through water use permits. DNR reviews water use permit applications to determine potential effects on prior appropriators. In coastal areas water use may cause saltwater intrusion by over-pumping a coastal aquifer or drilling the well too close to the coast. DNR requires water well contractors to submit well logs for all drilled wells and sets water well standards.

Coal Mining

Extensive groundwater investigation and monitoring requirements govern surface coal mining (11 AAC 90). These requirements include performance standards on groundwater monitoring, groundwater protection, maintaining the hydrologic balance, water quality standards, protection of groundwater recharge capacity, and alluvial valley floor requirements.

LOCAL GOVERNMENT AUTHORITIES

Municipal Authorities

Unified Home Rule, and First and Second class boroughs may exercise powers to provide areawide water pollution control (Alaska Statute 29). Borough ordinances defining the assumption of these powers must be at least as stringent as relevant state regulations. Boroughs are required to provide planning and zoning. Through these powers boroughs develop comprehensive plans controlling development within the borough, develop land use ordinances to implement the comprehensive plan, and establish platting requirements for the subdivision of land. Cities within a first or second class borough may, by ordinance, assume planning and zoning powers.

Municipalities have the authority to adopt an ordinance to protect their water supply and watershed, and may enforce the ordinance outside their boundaries (AS 29.35.020(b)). However, when the watershed lies outside of the municipality, they must have the approval of the adjoining municipality, if there is one. This gives local governments the ability to protect their municipal water supply, either surface water or groundwater, independently of the authority of other state agencies.

To date (1987) only the Municipality of Anchorage (MOA) has assumed limited water pollution control authorities. MOA regulates on-lot wastewater disposal systems, single family water well construction, and conducts water quality monitoring within the Municipality. MOA voters approved two bond issues, in 1984 and 1986, to support investigation and monitoring of water quality, and construction projects to improve water quality. As part of the water quality monitoring, approximately 80 monitoring wells were installed and are sampled periodically to determine trends and changes in groundwater quality.

Indian Tribes

Recent amendments to SDWA, CERCLA, and CWA include provisions for the federal government to provide Indian tribes with the same rights as states in assuming federal programs. This means EPA would administer programs such as the public drinking water program in tribal areas or EPA could delegate the program to the tribe to administer. In either case the state would not have direct input into the administration of the program. At present Metlakatla is the location of the only Indian tribe in Alaska.

The SDWA establishes four broad tests to define an Indian tribe. First, the Indian tribe must be recognized by the Secretary of the Interior. Second, the Indian tribe must have a governing body carrying out substantial governmental duties and powers over a defined area. Third, the functions to be exercised by the Indian tribe must be within the area of its jurisdiction. Fourth, in EPA's judgement, the Indian tribe must be reasonably capable of carrying out the functions necessary to administer SDWA programs effectively and in a manner at least as protective of public health as maintained by a state (Federal Register Vol 52. No. 143 P. 28112).

EVALUATION OF CURRENT AUTHORITIES

Current groundwater protection authorities comprise seven major federal laws which include varying source control and groundwater monitoring requirements. These laws form the basis for the majority of state programs. State authorities include broad direction for protection of public health and the environment. Local governments have authority to carry out local groundwater protection efforts. The existing state authorities provide sufficient coverage for state agencies to develop source control programs and require sufficient groundwater protection measures (Table 1).

Strengths of Existing Government Authorities

Numerous areas exist within current authorities and regulations that provide for

TABLE 1. Agencies and Local Governments with Statutory or Regulatory Authority Regarding Groundwater Quality Protection in Alaska

Activity	DEC	EPA	DNR	AOGCC	DOTPF	MOA
National Pollution Elimination Discharge System		X				
Water Quality Standards	X	X				
Groundwater Classification	X			X		
Solid Waste Disposal	X	X				
Domestic Wastewater Disposal	X					X
Nondomestic Wastewater Disposal	X	X	X	X		
Surface Impoundments	X	X	X	X		
Hazardous Waste Disposal	X	X				
Transportation of Hazardous Waste		X			X	
Underground Injection of						
- Nonhazardous Wastes	X	X	X	X		
- Hazardous Wastes		X				
Oil and Gas Wells			X	X		
Fertilizer Application			X			
Pesticide Application	X	X				X
Oil Storage						
- Above Ground Tanks	X	X				
- Underground Tanks	X	X				
Coal Mining			X			
Industrial Materials Storage	X	X				
Oil and Hazardous Substance Spill Response	X	X				
Appropriation of Water			X			
Public Drinking Water Wells	X	X	X			
Private Drinking Water Wells	X		X			X
Protection Planning						
Wellhead Protection	X	X	X			X
Aquifer Protection	X		X	X		X

DEC---Department of Environmental Conservation
EPA---U.S. Environmental Protection Agency
DNR---Department of Natural Resources
AOGCC---Alaska Oil and Gas Conservation Commission
DOTPF---Department of Transportation and Public Facilities
MOA---Municipality of Anchorage

groundwater protection. The majority of existing source control programs and public water supply regulation are within one department, DEC. This is a major benefit in coordinating improvement in existing regulations. Groundwater is specifically included in the water quality standards (18 AAC 70.020). Through the inclusion of groundwater in the standards, any activity, whether regulated or not, which causes a degradation of water quality can be cited for a violation. This is a major strength, because some states do not include groundwater in water quality standards, and therefore have limited regulatory means to cite operations which contaminate groundwater.

Alaska has a state-funded "Superfund" to pay for site investigations of groundwater contamination. DEC and Municipalities have broad authority to implement water source protection actions to protect drinking water sources.

Overlaps Between Agencies and Regulations

Instances exist in which two agencies, or programs within an agency, have the same or similar statutory responsibility, or through regulation have overlapping duties. Improved coordination in the areas of overlap can streamline the regulatory process. Data collection is one of the main areas of overlap between agencies. DEC requires that water well logs, pump test data, and water quality data be submitted for public water system plan review. Most of this data is also required by DNR's Division of Land and Water Management in processing water rights applications. Similarly, DNR's Division of Geological and Geophysical Surveys collect, analyze, and disseminate geologic and water quality data.

The Alaska Oil and Gas Conservation Commission (AOGCC) may regulate "for conservation purposes the contamination or waste of underground water" (AS 31.05.030(e)) as it relates to oil and gas exploration and development. This overlaps with DEC's authority to control, prevent, and abate air, water, or land or subsurface land pollution (AS 46.03.020(10)(A)).

Gaps in Existing Authorities or Regulations

A gap is defined as a need for a statute or regulation to control an activity which has contaminated groundwater or has a significant potential to contaminate groundwater. During 1988 EPA will finalize the federal Underground Storage Tank regulations. These regulations will not apply to above ground petroleum storage tanks. Prevention-oriented regulations need to be developed for the above ground storage of petroleum products.

Monitoring wells are required in several different source control programs, however, there are no regulations to set minimum performance standards for monitoring well construction. Water quality standards set permitted values for contaminants in water or provide narrative descriptions of standards. There are no standards which address permitted contaminant levels in soils.

Improvements in the Existing Regulations

Existing regulations should 1) include new information on toxic effects of chemicals, 2) be updated within the next three to five years for changes in federal regulations, and 3) be revised to specifically include groundwater monitoring requirements. In most cases current regulations implicitly provide for groundwater protection, however, to be more uniformly enforced the regulations should explicitly define groundwater protection requirements.

One of the primary areas for improvement is revising and developing guidance for field staff describing groundwater protection considerations in reviewing permit applications and during for spill response. The solid waste regulations were recently revised. Guidance should be developed to ensure consistent statewide application of these regulations. The Wastewater Disposal regulations should be revised to include requirements for monitoring wells in areas where there is a significant potential threat to public health or the environment. Specific language should be added to the wastewater regulations banning the introduction of hazardous or toxic substances into wastewater disposal systems.

The oil spill contingency plan regulations should be revised to include requirements for monitoring well placement, groundwater sampling, and reporting of water quality under regulated facilities. The Drinking Water regulations should be amended to include the revised maximum contaminant levels as soon as EPA has finished developing them. Drinking water regulations should be revised to require, during design and plan review, a more detailed consideration of the vulnerability of underground drinking water sources to contamination. Water well construction and abandonment regulations should be revised.

Under the current water quality standards contaminant levels for aquifer remediation are described by numeric or narrative standards. Procedures need to be developed to ensure consistent approach and enforcement of aquifer remediation efforts statewide.

CONCLUSIONS

An advantage of the present groundwater quality protection regulatory framework is that the majority of source control programs are administered by one department (DEC). The major control programs outside DEC include Underground Injection Control Class II Wells associated with oil and gas production (AOGCC), coal mining and related development (DNR), and control of water use to limit saltwater intrusion (DNR). This is in contrast to many states where regulation of public drinking water systems, solid waste disposal, underground storage tanks, hazardous wastes, and groundwater protection planning are within three or more separate departments. The existing Alaskan agency structure is one of the more efficient in the nation to deal with groundwater protection.

DEC and DNR have sufficient statutory authority to amend existing regulations and develop additional regulations to ensure protection of the groundwater resource. Local governments have sufficient statutory authority to improve and develop local ordinances for groundwater protection. Major areas for improvement include revising oil pollution control regulations to be consistent with the EPA UST regulations, once the EPA regulations are finalized in 1988.

Standard procedures should to be revised or developed for the administration of solid waste and wastewater regulations with respect to evaluating the potential impact of the facility on groundwater quality. Additional training is required for agency and industry staff in recent advances in groundwater protection methods to incorporate into facility design, safety considerations during site investigations and sampling, and groundwater sampling methods.

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SURFACE WATER ISSUES

CALIBRATION AND VERIFICATION OF A ONE-DIMENSIONAL FLOW MODEL TO THE KNIK AND MATANUSKA RIVERS, SOUTHCENTRAL ALASKA

by Stephen W. Lipscomb[1]

ABSTRACT

The lower reaches of the Knik and Matanuska Rivers merge in a complicated system of interconnected channels, some of which convey water only during higher flows. This reach is subject to unsteady flow conditions which result from a semidiurnal tide wave propagated up the channels from Cook Inlet. The tidal range in Cook Inlet is among the largest in the world, decreasing from 35 feet at Anchorage (30 miles from the study area) to approximately 10 feet at the Glenn Highway crossing.

The Geological Survey's branch-network flow model (BRANCH) was used to simulate flows within the study reach. The model was calibrated and verified using measured discharge data obtained at the four lower boundary sites. The calibration was done using a single time-series of measured discharge data collected over a complete tide cycle. Simulated discharge was calibrated to within 10 percent of the measured values. Verification of the model calibration was done using a second data series. The simulated values showed good agreement with the measured data over some ranges of discharge; however, further calibration would likely improve the results.

The BRANCH model is a well documented and versatile model capable of handling both steady and unsteady flow regimes. The BRANCH model can supply streamflow information to various transport models such as QUAL-II and the Lagrangian Transport Model to simulate the transport, dispersion, and interaction of various constituents that affect water quality in rivers. These models are driven by time-dependent streamflow input which can be supplied by the BRANCH model.

INTRODUCTION

Rapid growth in population and development in the Palmer-Wasilla area during the past 5 years have led to an increase in traffic along the Glenn Highway between Anchorage and this area (FIGURE 1). In an effort to relieve traffic congestion, the Alaska Department of Transportation and Public Facilities (ADOT&PF) has begun making plans to widen the Glenn and Parks Highways between Eklutna and Wasilla. Included in this proposed plan is the construction of additional traffic lanes across the Eklutna flats. This would require construction of additional bridges across the Knik and Matanuska Rivers at the present Glenn Highway location just upstream from the Knik Arm of Cook Inlet. Hydraulic and hydrologic information not previously available for the proposed crossing site were needed to assist in design of the proposed new bridges and roadway.

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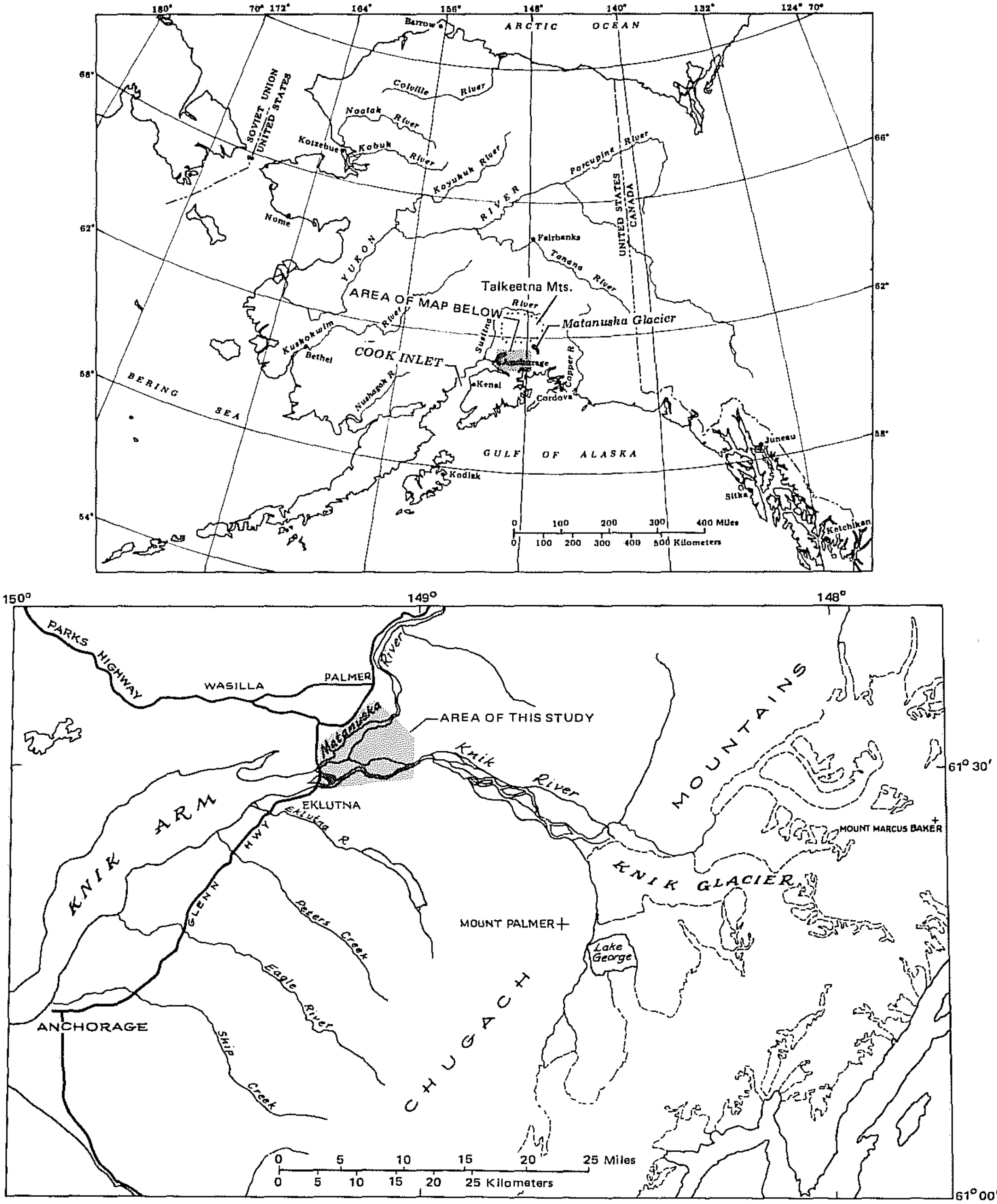

FIGURE 1. Location of Knik and Matanuska River study reach and upper Knik River basin.

Hydraulic analysis of the two rivers is complicated by several physical factors. The lower reaches of the Knik and Matanuska Rivers merge in a system of interconnected channels which allow the flow to take a variety of routes to the mouth at tidewater. This reach is also subject to unsteady flow conditions that result from a semidiurnal tide wave propagated up the channels from Cook Inlet. The tidal range (difference between low and high tide elevations) in Cook Inlet is among the largest in the world, decreasing from 35 ft at Anchorage (30 mi from the study area) to approximately 10 ft at the Glenn Highway crossing. This tidal influence can be detected for several miles upstream from the mouth of the rivers.

The U.S. Geological Survey's branch-network flow model (BRANCH) (Schaffranek and others, 1981) was applied and calibrated to the Knik- Matanuska River system. This one-dimensional, implicit, finite-difference model is designed to simulate unsteady flow in rivers composed of networks of interconnected channels. The implementation of this model requires the input of channel geometry data at critical locations throughout the reach as well as time series of boundary-value stage and (or) discharge data at the upstream and downstream extremities of the study reach. These data were collected during the 1984 and 1985 summer field seasons and subsequently reduced to a format compatible with the model requirements. Model output is in the form of simulated discharges and water-surface elevations at the extremities of the reach as well as at intermediate locations where channel geometry is specified. This paper gives a description of the model including the data required for implementation, the limitations of the model, and the means by which the model was calibrated.

BASIN DESCRIPTION

The Knik and Matanuska Rivers flow into an estuary at the upper end of the Knik Arm of Cook Inlet. The Glenn Highway crosses the rivers in an intertidal marsh area roughly at the transition between the tidal-affected reaches and the estuary.

The Knik River originates about 40 mi northeast of Anchorage on the glaciated northern slopes of the Chugach Mountains (FIGURE 1). It flows northwesterly from its headwaters until it eventually empties into the Knik Arm of Cook Inlet near the village of Eklutna. The Knik River basin is approximately 1,200 mi^2 in area and varies topographically from the rugged peaks at its headwaters to the broad glacially formed valley near tidewater. Altitudes range from 13,176-foot Mount Marcus Baker to sea level at Cook Inlet. Approximately 55 percent of the Knik River basin is covered by glaciers, which accounts for the high concentrations of suspended sediment found in the river during the summer months. A prominent feature of the upper Knik River basin is the Knik Glacier, which covers an area of 166 mi^2. This glacier is noteworthy because of its potential to create a large lake behind the terminus where it impinges against the eastern slope of Mount Palmer. The annual breakout of Lake George, whose outlet was temporarily blocked each year (until 1966) by Knik Glacier, typically produced floods an order of magnitude greater than peak flows in non-breakout years.

The Matanuska River also originates on the northern slopes of the Chugach Mountains at the terminus of the Matanuska Glacier. It flows westerly and then southwesterly toward Knik Arm, which it enters about a mile north of the Knik River mouth. The 2,100-square-mile Matanuska River basin is approximately 15 percent glaciated.

STUDY REACH

The study reach extends downstream from U.S. Geological Survey stream-gaging stations No. 15281000 and No. 15284000 on the Knik and Matanuska Rivers near Palmer, to where these rivers are crossed by the Glenn Highway (FIGURE 2). At the lower boundaries of the study reach (FIGURE 2), four channels are crossed by the highway -- the main stems of the Knik and Matanuska Rivers (gage sites 15281110 and 15281140), and two secondary channels (gage sites 15281120 and 15281130). Recorders at the gage sites provided stage boundary-value data which can be used alone or in conjunction with discharge data to drive the BRANCH model.

The Knik River reach is 7.3 mi in length from upper to lower boundaries with a fall in water surface elevation on the order of 15 to 20 ft over that distance. Throughout the study reach the river is characterized by a complex system of interconnected channels that meander through the 2-mile-wide flood plain.

The Matanuska River reach is about 11 mi in length with a fall in water surface elevation of more than 150 ft over that distance. The channel patterns of this reach are even more complex than those of the Knik. For this reason and because of the steep gradient between the upper and lower gage sites, the upper boundary of the Matanuska reach was relocated to a site about 8 mi downstream from gage site 15284000 (FIGURE 2).

TIDAL INFLUENCE

Cook Inlet experiences a semidiurnal tide with a period of about 12.5 hours; tide range reaches almost 35 ft at Anchorage. During high tide, a wave propagated up the lower reaches of the Knik and Matanuska Rivers produces unsteady flows. The range in stage can vary by 10 ft or more in the Knik River at the Glenn Highway crossing over a tide cycle. A typical cycle lasts 4 to 5 hours, depending on the magnitude of the tide. These periods of tidally induced unsteady flow are punctuated by periods of steady flow dominated by river discharge (FIGURE 3).

MODEL DESCRIPTION

The U.S. Geological Survey's BRANCH flow model (Schaffranek and others, 1981) was applied to the study reach to simulate flows and water-surface profiles. This particular model is based on one-dimensional, partial-differential equations of continuity and momentum which govern unsteady flow. For computational purposes these equations are replaced by implicit finite-difference equations which approximate the actual solution. The applicability of these equations is constrained by the following assumptions:

1. The channel slope is mild and constant over the reach length so the flow remains subcritical.

2. Lateral inflow or outflow between junctions is negligible.

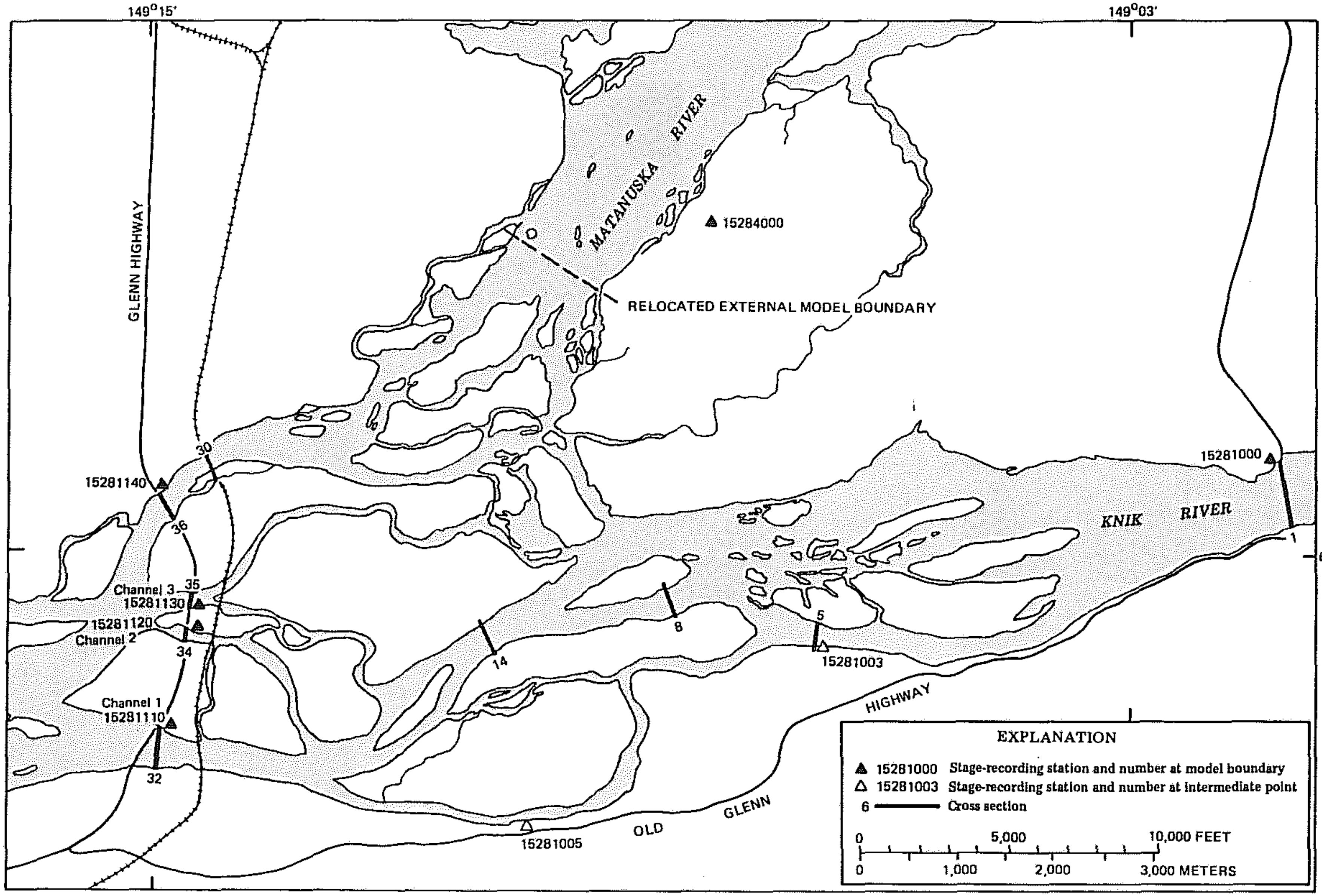

FIGURE 2. Location of data-collection stations and selected cross sections.

3. Mannings roughness coefficient ("n" value) is representative of frictional resistance in unsteady and steady flows.

4. The density of the flow is substantially homogeneous.

5. Hydrostatic pressure exists throughout the channel.

6. A reasonably uniform velocity distribution prevails throughout any cross section.

7. The channel beds are stable and not subject to significant scour or fill.

This model was selected for use on the Knik and Matanuska Rivers because of its ability to simulate unsteady flows and to accommodate river reaches comprised of networks of interconnected channels. It is also capable of accounting for point-source inflows and outflows within the modeled reach, the effects of wind shear on the water surface, and to some degree nonuniformity in the velocity distribution throughout a cross section.

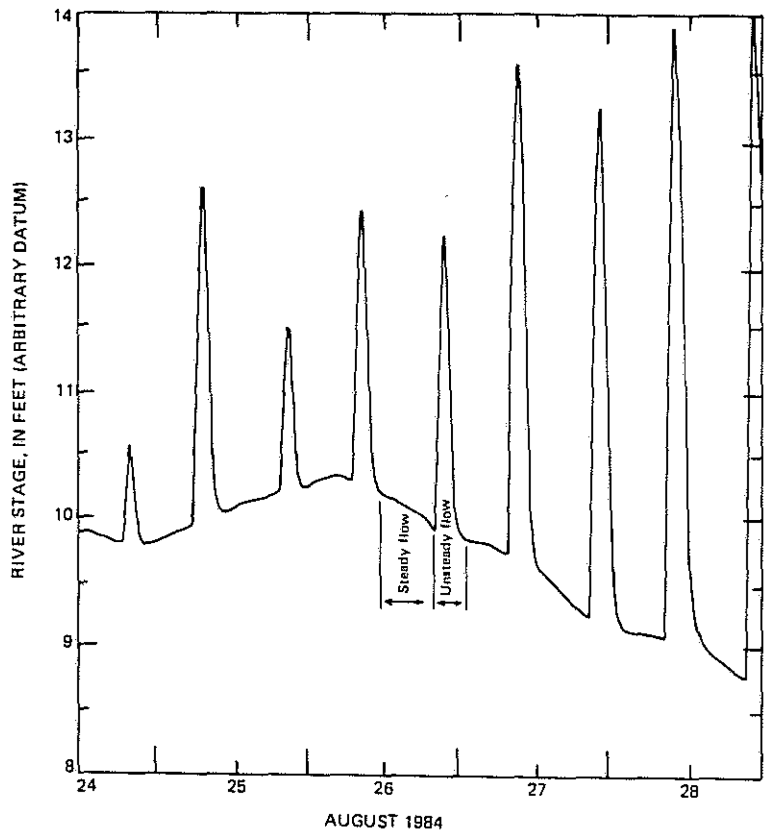

FIGURE 3. River stage of Knik River near Eklutna (15281110) showing steady and unsteady flow periods due to tide influence, August 24-28, 1984.

Three requirements must be met to develop a model of the prototype river using the BRANCH flow model.

1. The reach to be modeled must be properly represented or schematized to accurately depict the controlling features of the river.

2. Channel geometry information must be provided at the critical locations determined from the schematization procedure.

3. Boundary-value data, consisting of time-series of synchronous stage and (or) discharge data, must be provided at all external boundaries.

The accuracy of data furnished to fulfill each of these requirements is critical to the final accuracy of the model simulations. In addition to these requirements there are several computation control parameters that can be adjusted to facilitate calibration of the model.

Schematization

The aim of the schematization process is to identify the important controlling features of the study reach and include them in such a way as to represent their effect on the system. These features include external junctions which delimit the boundaries of the prototype reach, internal junctions where two or more channels either diverge or converge, branches which are the reaches between junctions, and the branch lengths. Other features that require definition are constricting or expanding reaches and locations where simulated data is sought once the model has been calibrated. For the purpose of this study the complete schematization of both the Knik and Matanuska Rivers consists of 6 external junctions, 19 internal junctions, and 33 branches (FIGURE 4).

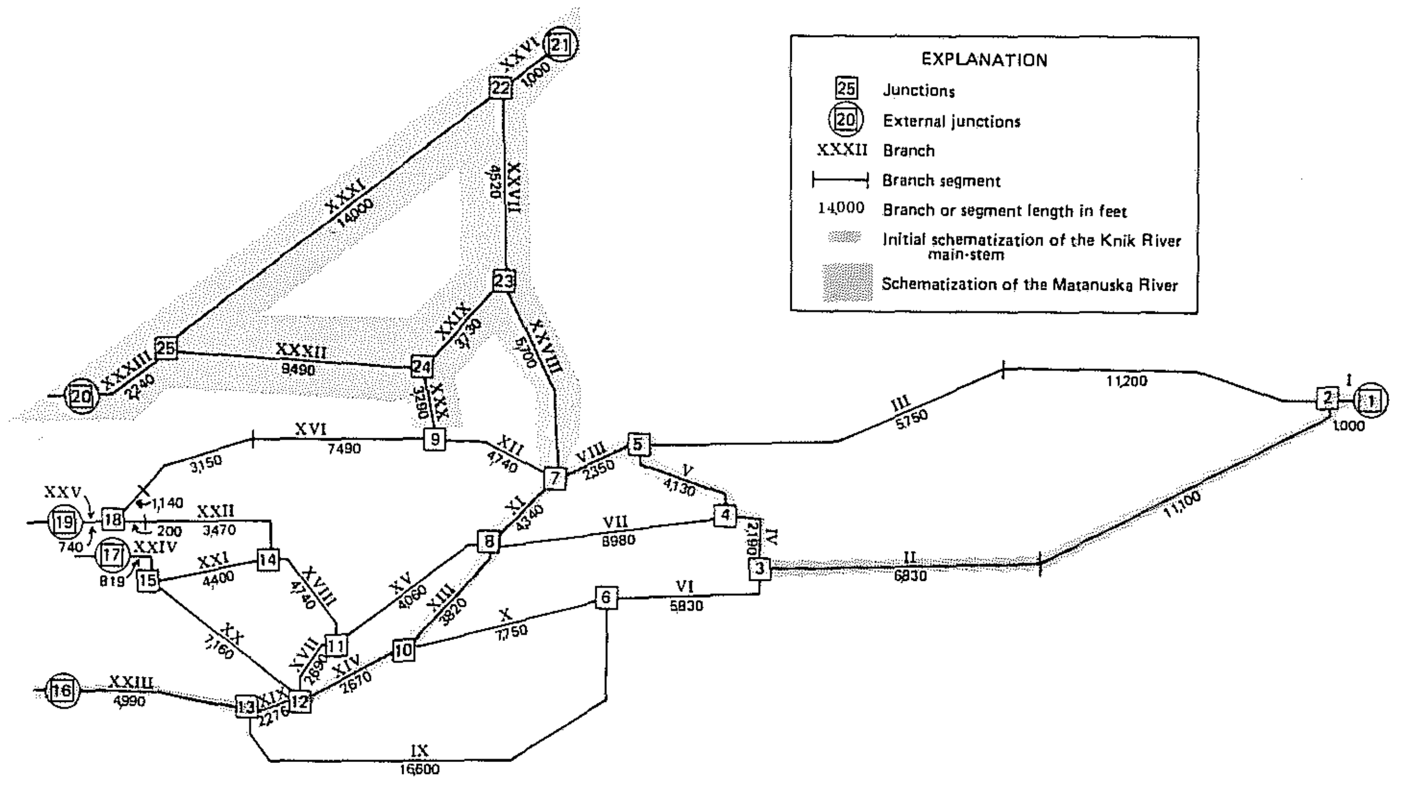

FIGURE 4. Schematization and branch lengths of the Knik and Matanuska Rivers for the branch-network flow model.

Channel Geometry

Certain hydraulic and physical properties must be specified at cross sections defined where external and internal junctions occur as well as at the termini of all segments. This information, in the form of stage versus area and stage versus top-width tables, is utilized by the model during computation. The channel geometry tables must cover a range in stage that includes all stages to be simulated.

Channel geometry data for the Knik and Matanuska Rivers were obtained by standard field surveying methods for portions of the cross sections above the water surface. In-channel depths were obtained using a recording fathometer and a moving boat. The distance from left to right edge of water was also determined and the data were used to define the cross section dimensions.

The model makes the assumption that all channels schematized in the modeled reach always contain water. The study reach, however, has overflow channels at several locations that in fact convey flow only at higher stages and are dry at lower stages. In order to accurately represent the prototype channel without causing the model to fail, some alteration to the actual channel geometry was necessary. This was accomplished by including an artificially deep thalweg or 'spike' in the channel configuration. This spike was constructed so as to be of negligible area so the integrity of the channel conveyance properties would be retained while still satisfying the constraints of the model (FIGURE 5, cross section 8).

Boundary-Value Data

The boundary-value data required to drive the BRANCH model consists of stage and (or) discharge data at all external junctions of the prototype river. These data must be precisely timed so that synchronous values can be provided to the model for use as boundary values. Boundary-value stage data for each site must be based on the same datum, which for this study sea level. Stage data are generally used because of the ease involved in collection. The stage records were timed using various types of solid-state clocks depending on the type of gage used at a particular location. The times recorded in conjunction with the stage data were checked before and after each set of boundary-value data was collected to insure their accuracy. Levels were also run to the water surface before and after collection of all stage data to insure the accuracy of the elevations.

Stage data were obtained continuously during the open-flow period at the Knik and Matanuska Rivers near Palmer (stations Nos. 15281000 and 15284000) and at the Knik and Matanuska Rivers near Eklutna (stations Nos. 15281110 and 15281140). Stage data were obtained at the two downstream secondary channels (stations Nos. 15281120 and 15281130) for several days preceding scheduled field trips and were collected during those same intervals at selected sites (stations Nos. 15281003 and 15281005) within the study reach. The stage data collected at these latter two locations were not required as model input but were used as an aid in the calibration of the model and in determining the extent of the tide-wave propagation up the channel.

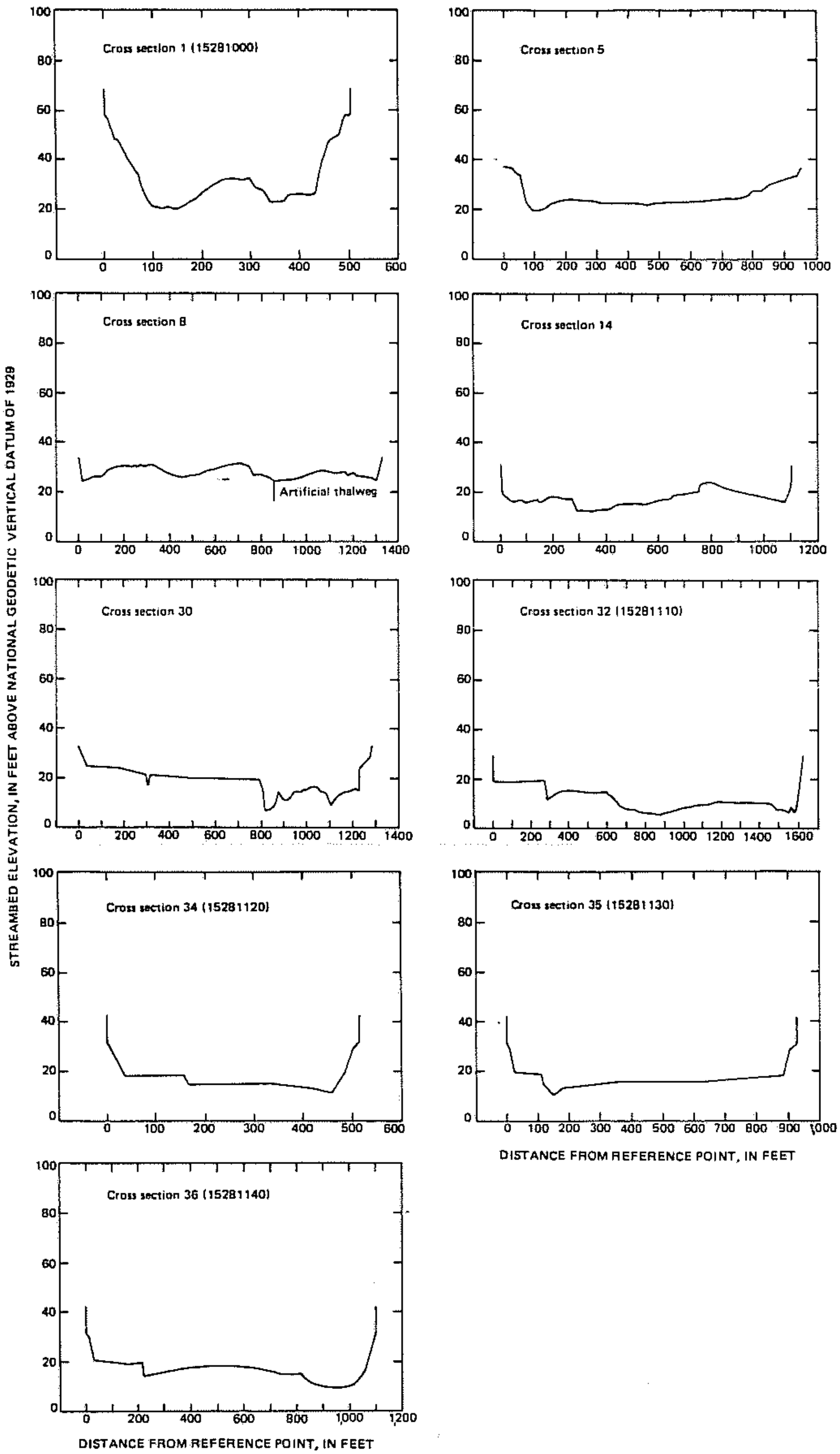

FIGURE 5. Selected cross sections of the Knik and Matanuska Rivers. (See figure 2 for cross-section locations.)

MEASUREMENT OF UNSTEADY FLOWS

In addition to the data required for model implementation it is also necessary to obtain sets of measured discharge data for calibration purposes. The measured data collected for this purpose consist of time series of discharge values obtained simultaneously at the four lower boundaries gage sites of the study reach (station Nos. 15281110, 15281120, 15281130, and 15281140). Standard procedures for making discharge measurements are not applicable due to the unsteady flow conditions that exist during tide cycles. FIGURE 3 illustrates the rapidly changing stage over time during the period that a discharge measurement was made on August 28, 1984.

In order to measure discharge during periods of unsteady flow, the channel was subdivided into approximately ten subsections based upon assumed centroids of flow. Buoys were moored at the center of each subsection for stationing, and velocity measurements were taken at 0.2 and 0.8 depth or 0.6 depth. Velocity measurements were made with a standard Price[1] current meter and sounding weight suspended from a boat. Precise notation of time was made during each measurement.

The discharge measurement was begun prior to the beginning of the tide cycle to obtain one complete set of velocity measurements at each subsection during steady flow conditions. Velocity and depth measurements were then continued in a cyclic manner from one side of the channel to the other during the entire period of the tide cycle. This procedure was carried out at all four downstream boundary channels simultaneously.

DISCHARGE COMPUTATION

Depth-time and velocity-time plots were constructed for each subsection within the channel. Areas were computed based on the depth-time plots and the subsection widths. Rapidly changing channel widths were accounted for when computing the areas of the left and right subsections. Using linear interpolation, the velocity, area, and discharge for each subsection were computed at 1-minute intervals for the complete time period of the measurement. The values for all subsections within a particular channel were then summed to obtain the instantaneous discharge at 1-minute intervals throughout the tide cycle. Discharge values at 15-minute intervals were used in the BRANCH model application as this was determined to be the desired simulation time step.

MODEL CALIBRATION AND VERIFICATION

Once the data requirements to represent the prototype river reach were satisfied, model runs were made to simulate stage and discharge at all locations within the reach where channel geometry was defined. At this point calibration of the model was initiated using measured discharge data as a basis for comparison with the model output. The goal of the calibration process is to adjust the parameters and coefficients that affect the models computation until the computed

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[1] Use of the trade names in this report is for identification purposes only and does not constitute endoresement by the U.S. Geological Survey.

output matches as closely as possible the measured data. These parameters and coefficients include such variables as eta values which essentially represent the channel roughness, chi and theta values that affect the the computational stability of the model, and a coefficient of momentum, or beta value, which accounts for non-uniform velocity distributions at a given cross section. The calibration may also require the adjustment of the water surface slope, cross-sectional area, and top widths. These adjustments are usually necessary when datum errors occur either in the cross-sectional geometry or the boundary-value data.

Satisfactory results were obtained during the initial runs, which included only the Knik River and the two secondary lower boundary sites (station Nos. 15281000, 15281110, 15281120, and 15281130). However, when the Matanuska River was included in the schematization, problems arose with computational instability. These problems were attributed to oversimplified schematization, inclusion of overflow channels with associated artificial thalwegs, steep gradients, and short reach lengths.

During model runs it was observed that at times the artificial channels which had been assigned to prevent drying our branches were shown to be conveying significant flows and causing undesirable circulation patterns and fluctuations of stage within the network. This instability was most pronounced at low stages and made calibration of the model in this range difficult. Because one objective of developing the model was to provide a tool for the analysis of flood flows, it was determined that calibration of the model in the higher ranges of stage was most critical. For this reason, the model was calibrated to measured data at higher stages only.

Steep channel slopes, especially on the Matanuska River, were also partly responsible for difficulties in calibrating the model. A basic assumption of the equations governing the unsteady flow computation is that the slopes are mild and constant throughout the reach length such that the flow remains subcritical. Due to the rapidly changing stage at the lower boundary of the study reach it is likely that the flows at some locations in the reach were in repeated transition between subcritical and supercritical, which likely produced some of the observed instability.

The documentation of the BRANCH model specifies that branch lengths on the order of 5,000 to 25,000 ft are optimum for simulation purposes. Branches shorter than this require correspondingly smaller simulation time increments. This is based on the Courant restriction, which states that the simulation time increment must be less than the ratio of the branch length to the wave celerity plus the flow velocity:

$$\Delta t \leq \frac{\Delta x}{|U \pm \sqrt{gH}|}$$

Although this restriction need not be rigidly adhered to in an implicit solution, as is used in the BRANCH model, it is still a valid index that should not be exceeded by more than a factor of five (Schaffranek and others, 1981). In the schematization of the Knik and Matanuska Rivers the majority of the branches are less than 5,000 ft long with some being out of necessity as short as 700 to 800 ft. As a result, the simulation time increment had to be reduced from 15 minutes as originally planned, to 5 minutes, and finally to 2 minutes.

Due to continued problems with instability, it was decided to eliminate the Matanuska River from the model and concentrate on calibrating the Knik River and the two secondary channels using the measured data from the three remaining lower boundary sites (station Nos. 15281110, 15281120, and 15281130).

The measured data set obtained on July 3, 1985 was initially used for calibration because it was collected at the highest steady discharge and seemed to give the most stable results. After a lengthy trial and error process, the calibration coefficients were set to give the best overall comparison between measured and simulated discharge.

Comparisons of measured and simulated discharge on July 3, 1985 for the three lower boundary sites are shown in FIGURE 6. In most cases the computed results are within 10 percent of the measured data and are usually within 5 percent. Once the model had been adjusted to produce these results for the July 3 data, it was run again using the data from August 28, 1984 to verify the calibration. The results from this run are shown in FIGURE 7. Although the comparison of measured and computed values are in good agreement over some ranges of discharge for channels 1 and 2 (station Nos. 15281110 and 15281120), it is apparent that further calibration is necessary. Channel 3 (station No. 15281130) results show the poorest agreement.

Further calibration of the model would require the collection of additional data sets, preferably at higher flow rates. With the additional data it would be possible to calibrate the model over a wider range of hydraulic conditions. In this case it was necessary to calibrate the model using only one data set and verifying it with the other. It is probable that the model could be improved by using a functional relation to define the roughness coefficient "eta" rather than a constant value as was used. This would account for changing channel roughness due to stage variations. Since the lower sites are subject to a wide fluctuation in stage due to tidal influence, the actual channel roughness is probably variable and would best be described by a functional relation. Again, however, to determine this relation would require several additional measured data sets obtained over a wide range in flow and tidal conditions.

APPLICATIONS

The purpose of developing this model was to provide a means for understanding the hydrodynamics of the Knik and Matanuska Rivers in their lower, tide-affected reaches. Specific applications of the model will be to route design floods through the rivers and observe the effect at key locations throughout the study reach. Locations of interest would be at the highway and railroad crossings near the lower boundary of the reach as well as areas of residential development further upstream.

The BRANCH flow model is a well-documented and versatile model capable of handling both steady and unsteady flow regimes. This makes it particularly attractive in applications involving tidal-affected flows, flows regulated for hydropower purposes, and reaches whose flows are influenced by wind tides or seiching in adjoining lakes. Singular reaches can be modeled as well as networks of interconnected channels such as the Knik and Matanuska Rivers. Another useful feature of the BRANCH model is the ease with which it can be linked with various transport models. Models such as QUAL-II (Roesner and others, 1977) and the

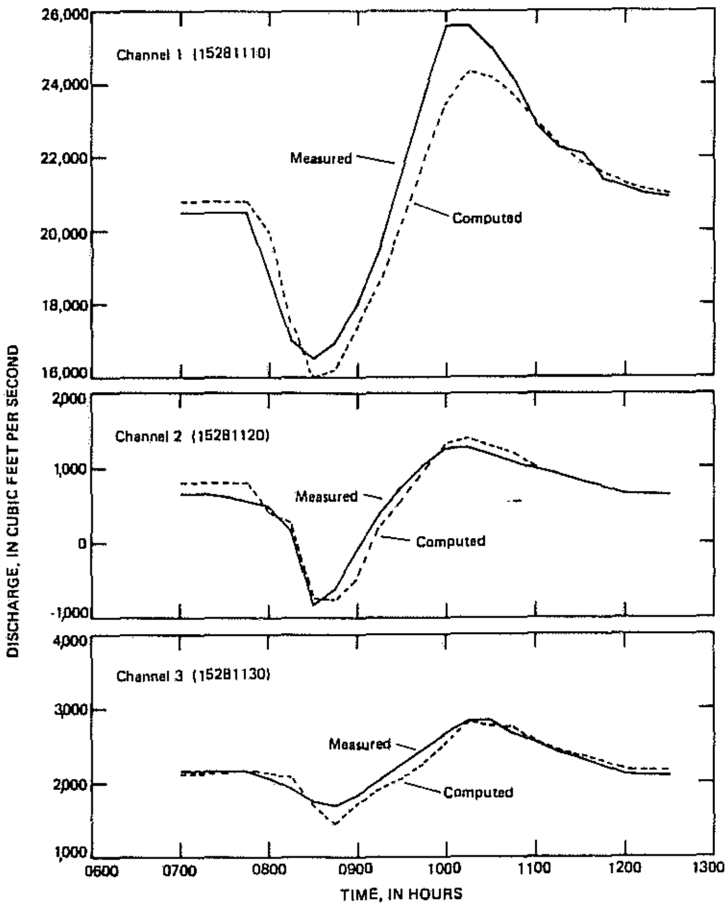

FIGURE 6. Comparison of measured and computed discharge for the Knik River near Eklutna on July 3, 1985. Data set used to calibrate model.

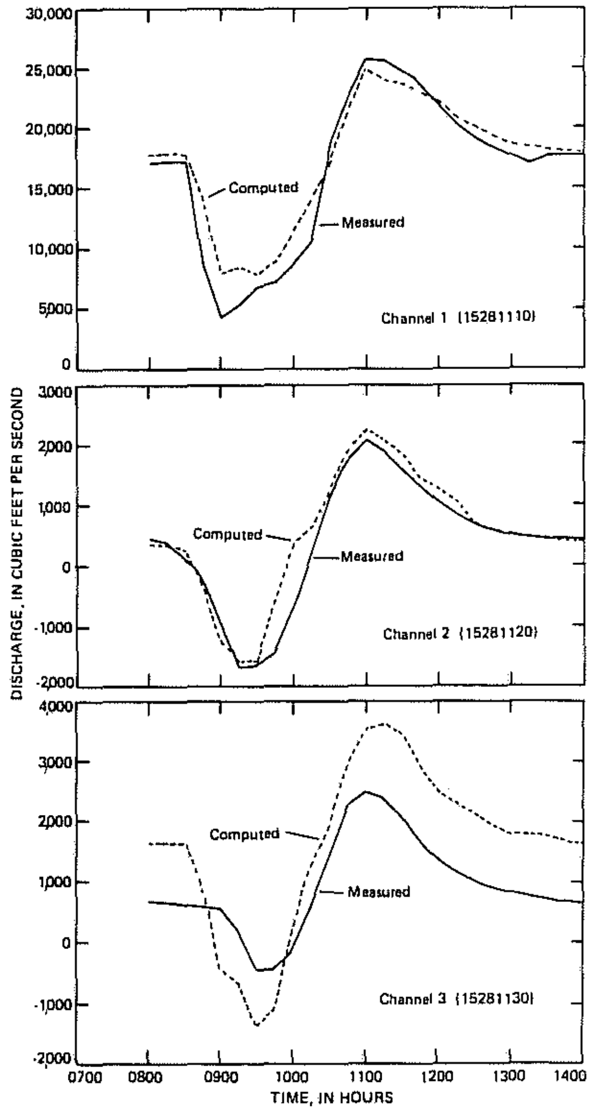

FIGURE 7. Comparison of measured and computed discharge for the Knik River near Eklutna on August 28, 1984. Data set used to verify calibration.

Lagrangian Transport Model (LTM) (Jobson, 1981) are used to simulate the transport, dispersion, and interaction of various water quality affecting constituents in rivers. These models may be driven by time dependent streamflow input computed by the BRANCH model.

SUMMARY

The Knik and Matanuska Rivers in southcentral Alaska merge near tidewater in a combination riverine-estuarine reach. In this reach the two rivers are characterized by a network of interconnected channels. Unsteady flows occur regularly in the lower reaches of these rivers due to the semidiurnal tides in Cook

Inlet. The branch-network flow model (BRANCH) developed by the U.S. Geological Survey was used to model the lower reaches of the two rivers. The limitations of the one-dimensional model dictate that flows up to bankfull stage could be simulated, but larger flows, such as those likely be produced by breakout of a glacier-dammed lake, could not be simulated.

ACKNOWLEDGEMENT

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BACTERIAL POLLUTION SOURCE INVESTIGATION IN ANCHORAGE STORM DRAIN SYSTEMS

by Larry A. Rundquist[1] and Keith E. Bandt[2]

ABSTRACT

Water samples were collected from sites along Fish, Chester, Meadow, Little Campbell, and Campbell Creeks and Eagle River in the Municipality of Anchorage for the purpose of identifying potential sources of bacterial pollution in these creeks. Detailed analyses were conducted on storm drain systems along Campbell, Chester, and Fish Creeks. Fecal coliform and fecal streptococci bacterial sampling was successfully used in storm drain systems during low flow periods to isolate point sources of pollution. This bacterial pollution investigation identified three locations of human point source pollution resulting from sanitary sewer connections to storm drain systems and eight locations of animal point source pollution due to a concentration of animals near a collector pipe or channel of the stream. Most of the remaining sites were suspected to be impacted to varying degrees by non-point sources of animal, and possibly in a few cases human, origin.

INTRODUCTION

The quality of the water in streams passing through the Municipality of Anchorage has been degraded by expanding urbanization over the past several decades. In 1984, the degradation was recognized to be critical enough that several streams were posted as potential health hazards, largely because of elevated levels of fecal coliform bacteria in the streams. A water quality sampling program was established for the purpose of identifying the sources of the pollution.

The methodology and a brief summary of the results of the entire program is presented. Additional details are presented for eight locations at which an expanded program was conducted to investigate the potential for point sources of contamination. The program illustrates the successful use of fecal coliform as a tracer element to identify sources of fecal contamination in storm drain systems.

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PREVIOUS STUDIES

A water quality sampling program was conducted in 1985 that formed the basis from which sites were selected for the sampling program described in this paper. The program began in May 1985, when the Municipality of Anchorage Department of Health and Human Services (DHHS) and the Alaska Department of Environmental Conservation (ADEC) organized a volunteer water quality sampling effort along six streams in the Municipality of Anchorage. Trained and supervised volunteers collected water samples at 184 potential sources of contamination to the streams, such as storm drain outfalls, drainage ditches, and tributaries. Samples were also collected at the inlet and outlet of extensively culverted sections of the stream in order to evaluate the potential for intervening sources. Water samples were analyzed for fecal coliform and fecal streptococci content and some were also analyzed for metals.

Results of the sampling program revealed that 49 of the 184 sites had high potential as sources of pollution input to the streams on the basis of moderate to high concentrations of bacteria or metals, or had relatively high fecal coliform to fecal streptococci (FC/FS) ratios. With appropriate sampling and laboratory analysis conditions, a FC/FS ratio greater than 4.0 may be an indication of human pollution while values less than 1.0 indicates that the source may be from domestic animals (Tchobanoglous and Schroeder, 1985). Values of the ratio between 1.0 and 4.0 provide no indication of whether the source is human or animal. Two additional sites were selected by DHHS and ADEC as potential pollution sources based on previous sampling results, bringing the total number of sites identified as potential pollution sources to 51.

DHHS contracted with S & S Engineering and Entrix, Inc. to collect additional samples during the fall of 1985 to further investigate the sources of pollution to three of the streams. Of the 51 sites identified as having high potential as pollution sources, 17 were investigated by S & S Engineering, 13 were investigated by Entrix, Inc., 4 were investigated by DHHS, and 17 of the sites were not assigned for immediate investigation.

S & S Engineering collected 147 samples to investigate potential sources of pollution at the 17 sites assigned to them. Results of the testing indicated that (S & S Engineering 1985):

- five sites were greatly affected by pollutants originating from animals at the Alaska Zoo
- five sites were greatly affected by horse farms, three of which may have had a human component
- four sites had pollutants that were attributed to animal nonpoint sources, one of which may have had an additional human waste component
- three sites had no source identified

S & S Engineering concluded that a long-term monitoring program should be established because of the inconsistencies and fluctuations in the data sampled over a short time period. Continued monitoring of the known problem areas would establish background levels and enable investigators to identify bacteria contamination sources. Further study of seven of the sites was recommended.

Entrix, Inc. collected 142 samples to investigate potential sources of pollution at 12 sites. One of the 13 sites assigned to them was found to be at the same location as another site, so the sites were combined. The results indicated that (Entrix, 1985):

- one site was affected by a residential sewer line connected to the storm drain system
- one site was affected by a ditch containing dog feces that drains directly into the stream
- three sites had pollutants that were attributed to nonpoint sources
- two sites had pollutants attributed to non-human sources
- five sites had no source identified

Entrix, Inc. concluded that, except for the one site which was definitely found to have a human point source, sites with high bacteria levels were probably a result of nonpoint runoff of animal fecal material. Large pet populations in Anchorage were suspected to contribute substantially to bacterial pollution problems in surface waters. The study recommended community education and laws on pet pollution, or removal of stormwater discharges to streams to alleviate the pollution problem.

DHHS collected additional samples at sites selected from the original 51 sites during March and April, 1986. Results from these samples and from the studies conducted during 1985 were evaluated by DHHS to select 28 of the 51 sites for continued study. Sites were selected for further investigation if no source had previously been identified and if they met either or both of the following criteria:

- moderate to high bacteria levels that were persistent and reproducible
- evidence of potential point source pollution

The remaining 23 of the 51 original sites were given a lower priority for continued investigation.

In July 1986, OTT, acting as subcontractor to James M. Montgomery, Consulting Engineers, Inc. (JMM) under contract to DHHS, was directed to evaluate the available information on the 28 sites selected for further investigation in order to select a group of storm drain sites that would require additional sampling to identify the source of the pollution. Four of these sites were selected by DHHS for additional investigation by DHHS staff. The evaluation of the remaining 24 sites by OTT resulted in the following conclusions (Montgomery and OTT, 1987):

- seven sites were eliminated from further sampling because their location in open drainage ditches, within extensively culverted sections of the stream channel, or within tributary streams did not meet the objective of selecting sites at storm drain outfalls

- six sites were eliminated from immediate sampling since the pollution was in the form of high zinc values rather than high bacteria levels
- two sites were assigned a low priority for immediate sampling since the bacteria levels were lower than the remaining sites
- nine sites were selected for additional sampling (two of the sites were at the same location, resulting in eight different locations)

The eight locations selected for further analysis are identified on Figure 1.

METHODS

The first two steps in the OTT evaluation were to review the existing data and to collect four sets of samples during a storm event on August 7 and 8, 1986 in order to further prioritize the sites. Two sites (D-6B/E-1 and 20-A) were given a top priority status, four sites (UA-1, CW-10, E-3, and E-4) were given a secondary priority status, and two sites (A-4 and I-4E) were eliminated from further sampling since they were dry during the August sampling.

The storm drain systems for the six sites for which additional sampling was conducted are shown in Figure 2. The number of sampling locations in each storm drain system and dates of sampling are summarized in Table 1. The dates were selected during times of low flow to avoid the sampling of surface runoff from rainfall events and the resulting nonpoint source pollution.

Table 1. Number of sampling sites and dates of sampling.

Storm Drain System	Number of Sampling Sites	Dates of Sampling
D-6B/E-1	14	8/17/86
20-A	19	8/14/86, 8/21/86 A.M., 8/21/86 P.M.
UA-1	3	1/15/87, 1/18/87
CW-10	6	1/15/87, 1/18/87
E-3	1	1/15/87, 1/18/87
E-4	1	1/15/87, 1/18/87

The methodology used to sample the storm drain systems consisted of collecting samples in manholes located wherever the system branched or where there was inflow from a catch basin into a manhole. In this way, potential sources of contamination could be methodically traced up the system. In each manhole sampled, samples were carefully collected by reaching upstream into the source pipe so that no mixing occurred with the combined flow in the manhole. Samples were stored on ice until delivery to the lab.

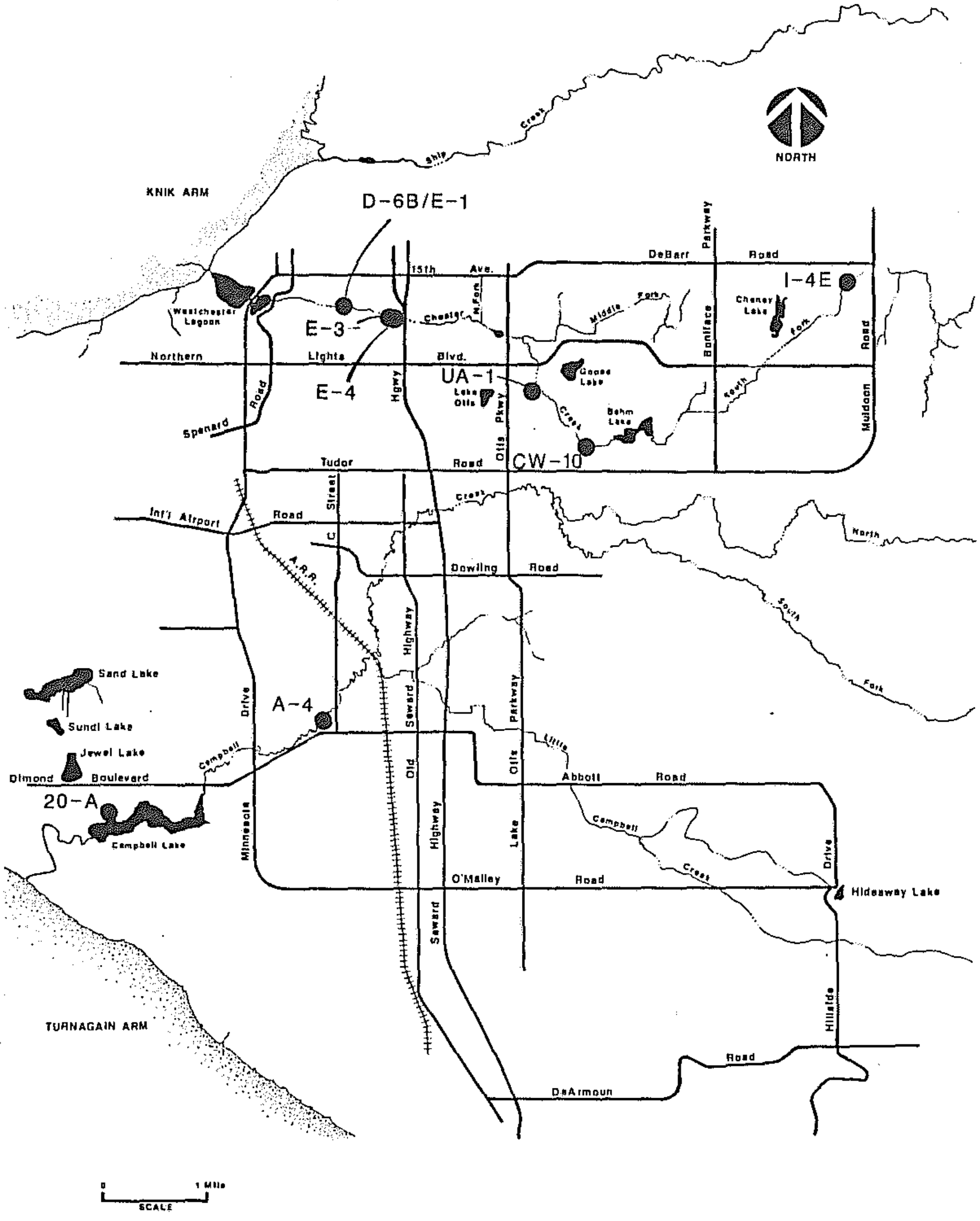

Figure 1. Location map showing eight sites for further analysis

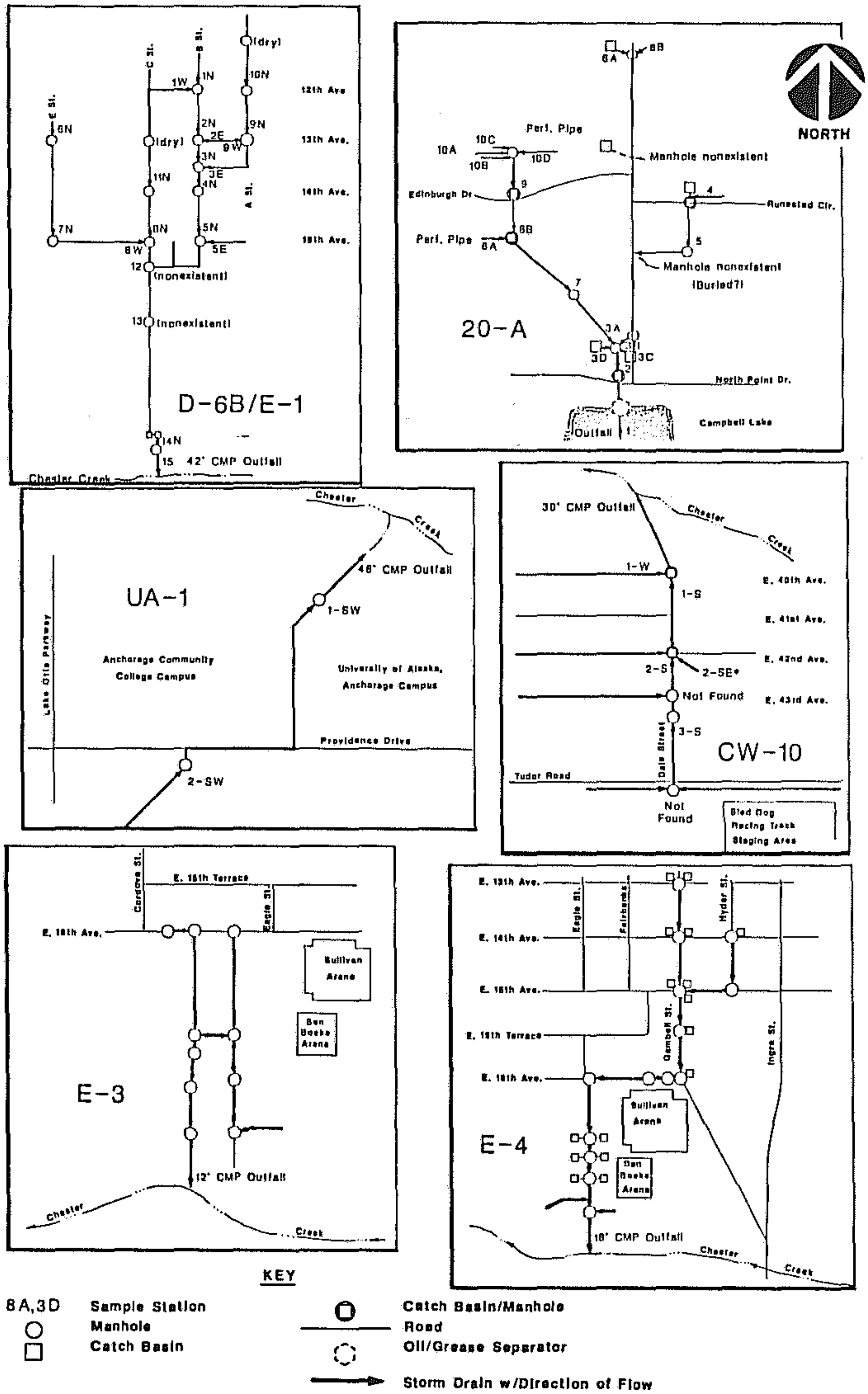

Figure 2. Sketches of storm drain systems for six sites with additional sampling.

In one location, anomalously high bacterial values prompted an inspection of the storm drain using a video camera. The camera was sent through the storm drain while documenting the position of the camera as it relates to the videotape.

RESULTS

The results of the sampling program conducted by OTT in August 1986 and January 1987 are summarized in Table 2. Data from the August 7 and 8 sampling indicates the following:

- o D-6B/E-1 and 20-A had bacteria counts much higher than other sites and were given the highest priority
- o UA-1, CW-10, E-3, and E-4 had moderate bacteria counts and were given secondary priority
- o A-4 and I-4E were dry during sampling making it unlikely that sanitary sewer connections are the sources of pollution at these sites and further investigations were not conducted
- o bacteria concentrations generally increase with increasing flow from storm runoff

The data collected during both the August and January sampling periods indicate that all FC/FS ratios which are valid (where FS counts exceeded 100) were less than 1.0, suggesting that the sources of contamination may be of non-human origin.

The data in Table 2 support the following results at the six sites for which continued investigations were conducted:

- o D-6B/E-1 (top priority)
  - stations upstream of sampling point 5E had consistently low bacterial concentrations
  - sampling station 5E had an anomalously high bacterial concentration
  - sampling locations 14N and 15 had high bacterial concentrations and were located downstream of sampling site 5E
  - a video camera inspection of the storm drain upstream of sampling point 5E identified a sewer connection to the storm drain
- o 20-A (top priority)
  - bacteria concentrations varied greatly even though the samples were collected during baseflow conditions
  - an increasing trend is evident in the downstream direction in the storm drain system
  - high bacteria counts at sampling points 3B and 3C corresponded with observations of several dogs on leashes near these catch basins
- o UA-1 (secondary priority)
  - a less dense sampling network was selected for this site

Table 2. Summary of results of Ott sampling program.

SITE/ SOURCE	DATE	STORM DRAINAGE FLOW (GPH)	FC	FS	FC/FS RATIO
20-A/ OUTFALL	8/07/86	9	0	53,000	0.0
"	8/08/86	72	1,600	>2,000	-
"	8/08/86	13	870	>2,000	-
"	8/08/86	5	850	>2,000	-
1	8/14/86		750	1,310	0.6
"	8/21/86		38	330	0.1
"	8/21/86		6	280	0.0
2	8/14/86		380	910	0.4
"	8/21/86		62	530	0.1
"	8/21/86		56	800	0.1
3A	8/14/86		290	660	0.4
"	8/21/86		36	210	0.2
"	8/21/86		20	270	0.1
3B	8/14/86		100	1,140	0.1
"	8/21/86		32	2,000	0.0
"	8/21/86		40	2,600	0.0
3C	8/14/86		2,330	1,200	1.9
"	8/21/86		400	1,900	0.2
"	8/21/86		1,000	1,500	0.7
3D	8/14/86		50	100	0.5
"	8/21/86		8	4	2.0*
"	8/21/86		6	6	1.0*
4	8/14/86		120	710	0.2
"	8/21/86		10	36	0.3*
"	8/21/86		<2	24	-
5	8/14/86		100	460	0.2
"	8/21/86		6	104	0.1
"	8/21/86		2	78	0.0*
6A	8/14/86		30	40	0.8*
"	8/21/86		20	130	0.2
"	8/21/86		24	200	0.1
6B	8/14/86		0	660	0.0
"	8/21/86		42	1,200	0.0
"	8/21/86		10	560	0.0
7	8/14/86		140	570	0.3
"	8/21/86		10	270	0.0
"	8/21/86		4	310	0.0
8A	8/14/86		0	30	0.0*
"	8/21/86		<2	<2	-
"	8/21/86		<2	<2	-
8B	8/14/86		100	420	0.2
"	8/21/86		8	80	0.1*
"	8/21/86		<2	64	-
9	8/14/86		160	440	0.4
"	8/21/86		4	6	0.7*
"	8/21/86		<2	2	-
10A	8/14/86		130	590	0.2
"	8/21/86		2	26	0.1*
"	8/21/86		<2	18	-
10B	8/14/86		130	750	0.2
"	8/21/86		4	4	1.0*
"	8/21/86		2	2	1.0*
10C	8/14/86		10	230	0.0
"	8/21/86		<2	18	-
"	8/21/86		<2	12	-
10D	8/14/86		0	10	0.0*
"	8/21/86		<2	<2	-
"	8/21/86		<2	<2	-

SITE/ SOURCE	DATE	STORM DRAINAGE FLOW (GPH)	FC	FS	FC/FS RATIO
D-6B/E-1/ OUTFALL	8/07/86	440	5,000	26,000	0.2
"	8/07/86	440(est)	3,700	7,400	0.5
"	8/08/86	403	2,960	>2,000	-
"	8/08/86	318	>2,000	>2,000	-
1N	8/17/86		0	0	-
1W	8/17/86		0	100	0.0
2E	8/17/86		20	100	0.2
2N	8/17/86		10	0	-
3N	8/17/86		70	0	-
4N	8/17/86		20	0	-
5N	8/17/86		70	2,000	0.0
5E	8/17/86		>20,000	13,500	-
8W	8/17/86		0	0	-
8N	8/17/86		0	0	-
11N	8/17/86		0	100	0.0
14N	8/17/86		1,280	5,800	0.3
15	8/17/86		1,390	600	2.3
UA-1/ OUTFALL	8/07/86	10(est)	30	30	1.0*
"	8/08/86	60	210	1,020	0.2
"	8/08/86	60	110	890	0.1
"	8/08/86	45	40	460	0.1
"	1/15/87	-	30	50	0.6*
"	1/18/87	50	<10	50	-
1-SW	1/18/87	-	<10	<10	-
2-SW	1/18/87	25	<10	<10	-
CW-10/ OUTFALL	8/07/86	340	0	30	0.0*
"	8/08/86	285	230	300	0.8
"	8/08/86	74	150	10	15.0*
"	8/08/86	74	30	60	0.5*
"	1/15/87	-	<10	20	-
"	1/18/87	-	<10	10	-
1-W	1/18/87	0.1	<10	<10	-
1-5	1/18/87	100	<10	30	-
2-5E	1/18/87	50	<10	<10	-
2-5	1/18/87	50	10	310	0.0
3-5	1/18/87	50	10	40	0.2*
E-3/ OUTFALL	8/07/86	5(est)	20	30	0.7*
"	8/07/86	10(est)	0	0	-
"	8/08/86	31	570	10	57.0*
"	8/08/86	22	40	170	0.2
"	1/15/87	-	90	20	4.5*
"	1/18/87	DRY	-	-	-
E-4/ OUTFALL	8/07/86	<1	50	10	5.0*
"	8/07/86	<1	100	40	2.5*
"	8/07/86	5(est)	490	1,500	0.3
"	8/07/86	10(est)	70	310	0.2
"	1/15/87	DRY			
"	1/18/87	DRY			
A-4/ OUTFALL	8/07/86	DRY			
"	8/08/86	DRY			
I-4E/ OUTFALL	8/07/86	DRY			
"	8/08/86	DRY			

* FECAL STREPTOCOCCI COUNT IS LESS THAN 100 - THEREFORE RATIO VALUE IS QUESTIONABLE

- samples had uniformly low bacterial content during the winter low flow sampling period

- CW-10 (secondary priority)
  - a less dense sampling network was selected for this site
  - samples had uniformly low bacterial content during the winter low flow sampling period
  - the field team observed that the drainage from the sled dog racing track staging area and the yard of a residence with several dogs would drain into this storm drain system during storm events
- E-3 and E-4 (secondary priority)
  - both sites were found to be dry during one or more site visits
  - water in E-3 during the January 15 site visit was later attributed to backwater from the stream

DISCUSSION

The strong direct correlation between bacterial concentrations and storm drain flow at six sites which flowed during the storm event on August 7 and 8 demonstrated the flushing effect of storm events on pollutants. While such a flushing implied a strong influence by pollutants that contribute to the system in surface runoff, the pollutants also may have collected in the storm drain pipe between events. Collection of samples during periods of no precipitation minimized the influence of surface runoff, allowing other sources to become more evident. It is unlikely that storm drain systems which do not flow between runoff events have sanitary sewer connections, since sewers typically flow irrespective of storm events. It follows that the first step in attempting to document point source pollutants to storm drain systems would be to collect samples at only those systems which are flowing during periods of no precipitation. However, when the objective is to trace nonpoint pollutants to general localities, sampling should be conducted during events generating surface runoff to identify those areas contributing the greatest levels of bacteria concentrations.

A review of the FC/FS ratios illustrated the unreliability of using this ratio to differentiate between human and non-human sources. If samples with FS counts less than 100 per 100 ml were removed from the analysis, FC/FS ratios were generally less than 1.0, and never greater than 4.0. Even values in the D-6B/E-1 storm drain system downstream of the detected sewer connection did not exceed 4.0, although the sample immediately downstream of the sewer connection could not be determined. Since the FC count at this site was reported to be greater than a certain value, the resulting ratio can only be reported to be greater than 1.5. The poor reliability of using the FC/FS ratio to identify probable sources may be due to the relative die-off rate of bacteria; while the ratio may have some reliability if samples are collected at the source of pollution, the reliability decreases with increasing distance from the source because fecal coliform and fecal streptococci die at different rates, thus changing the ratio.

Results of sampling at site 20-A illustrate that even though there is great variation at a station and between stations during the three sampling trips during the August low flow period, trends are still evident in the data that indicate locations with anomalously high bacteria counts and trends through the system. It would follow that one set of samples well distributed throughout a storm drain system may be sufficient to identify the highest priority areas contributing pollutants to the storm drain system. Additional sampling would likely be required to isolate the contributor or to identify secondary priorities.

CONCLUSIONS

The results from the overall bacterial pollution investigation program and the detailed investigation of eight sites suggest the conclusions summarized in Table 3.

Table 3 Summary of conclusions from investigation of 51 sites

Conclusion	Number of Sites Affected			
	Little Campbell Creek	Campbell Creek	Chester Creek	Fish Creek
Dominant Pollution Source:				
-Sanitary Sewer Connection			2	1
-Animals at the Alaska Zoo	5			
-Horse Stables	2			
-Numerous Dogs			1	
-Animal Nonpoint Sources	8	2	13	
Possible Secondary Component:				
-Human Nonpoint Source	(3)		(2)	
-Animal Nonpoint Source			(1)	
Source Not Identified:				
-Low Bacteria/High Zinc Conc.	2	3		1
-Low Bacteria in One Sample		1	3	4
-Analyses Not Conclusive			2	1

Several general conclusions can also be made based on the results of the study:

- fecal coliform and fecal streptococci bacteria sampling can be successfully used to identify pollution sources within a storm drain system
- the ratio of fecal coliform to fecal streptococci is an unreliable indicator of pollution source and should not be relied upon as the only input to classifying the pollution as having human or non-human origin

- most contamination was identified as coming from animal nonpoint sources such as pet feces washoff, although a few point sources were identified

ACKNOWLEDGEMENTS

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OIL & GREASE SEPARATOR DESIGN CRITERIA
FOR URBAN DRAINAGE, ANCHORAGE, ALASKA

by James Davis MacInnis, Jr., P.E.[1] and Thomas R. Bacon[2]

ABSTRACT

To protect Anchorage's streams, oil & grease separators have been required on all storm drain outfalls. Until recently, however, standard criteria have not been available to insure that the separators functioned properly. Many separators have flushed oil and oil laden sediments during low intensity rainfalls. In addition, access to many of the separators has not been sufficient for routine maintenance activity. To resolve these problems the Municipality of Anchorage Department of Public Works, through R & M Consultants, Inc., interviewed other communities, conducted a literature search, and developed new criteria for oil and grease separator design. As a test case the new criteria was applied to the design of an oil & grease separator for an existing storm drain outfall into Campbell Creek near Clark's Way in Anchorage, Alaska.

INTRODUCTION

As the Anchorage urban area has grown, stream pollution problems associated with increased paved areas and automobile use have threatened the natural functions of the waterways. Oil and grease products are major pollutants associated with this growth.

For several years the Municipality has required the installation of oil and grease separators on storm drain outfalls. Until recently standard criteria have not been available to insure that the separators functioned as required. As a result, many separators have flushed oil and oil laden sediments during low intensity rainfalls. In addition, access to many of the separators has been inadequate for routine maintenance activity.

To resolve these problems the Municipality of Anchorage Department of Public Works, through R & M Consultants, Inc., interviewed other communities, conducted a literature search, and developed new criteria for oil and grease separator design. As a test case the new criteria was applied to the design of an oil & grease separator for an existing storm drain outfall into Campbell Creek near Clark's Way in Anchorage, Alaska.

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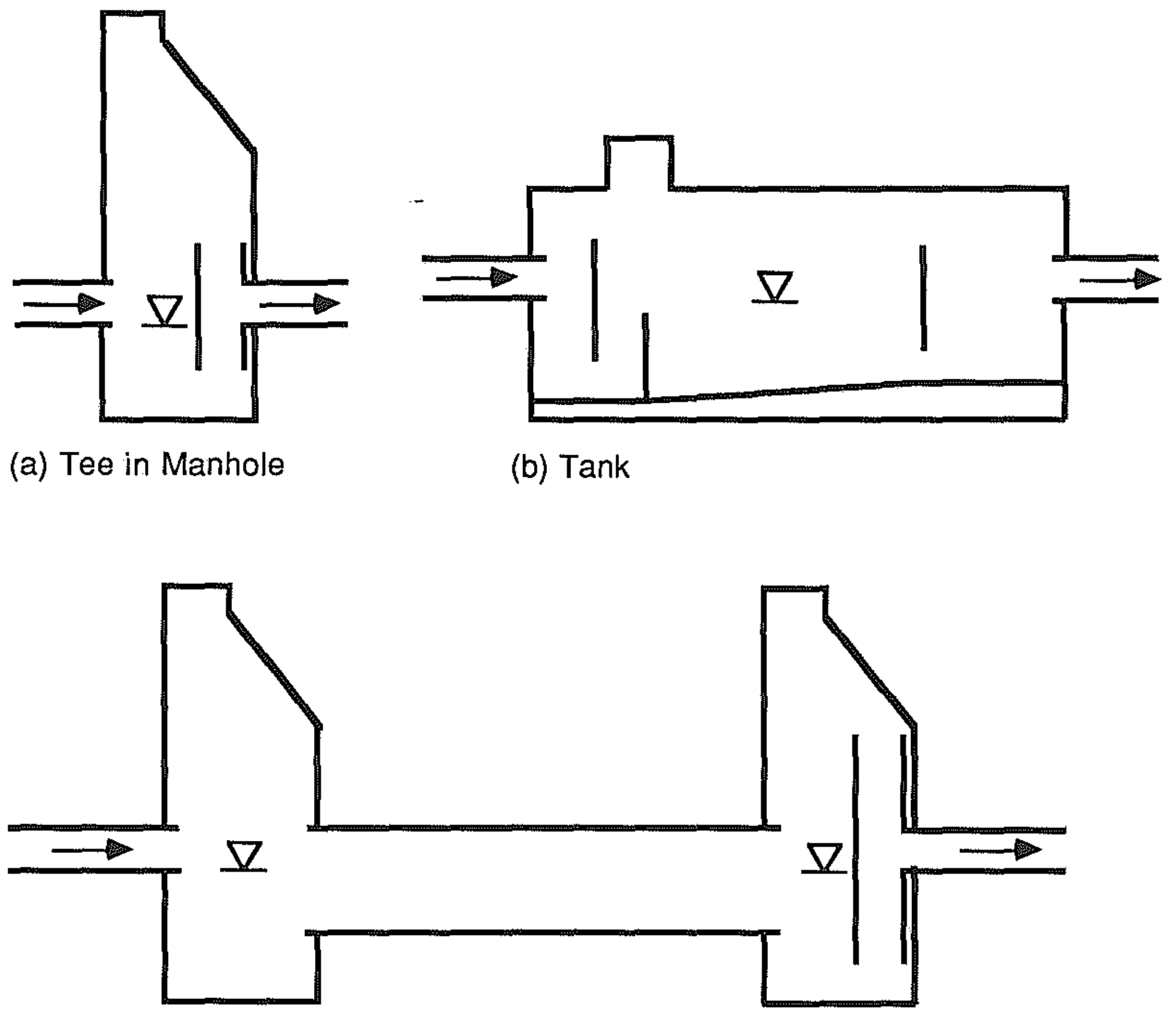
PAST DESIGN EFFORTS

By State law, the oil and grease content in any discharge to receiving waters cannot produce an odor or a visible sheen. The three most common design attempts to meet this requirement are briefly described below.


(a) Tee in Manhole

(b) Tank

(c) Oversize Pipe

FIGURE 1. Old Style Oil and Grease Separators

One approach to meet requirements for oil and grease removal was to place a pipe tee in the last storm drain manhole before the outfall (Figure 1). The design assumption was that the pipe tee would provide a pool of water in the manhole and that oil and grease would float on the surface of the pool. Due to the small overflow rate, sediment collection was limited, and except for very low flows the storage capacity of the separator was insufficient to retain and collect floating oil and grease.

A more substantial approach was a standardized tank separator installed at a storm drain outfall (Figure 1). The design objectives included removal of coarse sediments from storm runoff to reduce the sediment load to the receiving water. The tank capacity was greater than a pipe tee facility, but it functioned well only for relatively small outfalls. In addition, the tank lacked adequate access for maintenance activities and the purchase cost was substantial.

To reduce the expense of providing a tank separator, a design was developed that provided separator capacity equivalent to the tank, but at a lower cost. The capacity of the pipe tee in a manhole separator was increased by installing a larger pipe between the last two manholes. The tee in the last manhole provided a storage pool (Figure 1). Designs were calculated by assuming the overflow rate and volume of an equivalent tank installation.

Flushing of oil and grease from all three separator types has been observed at low flow conditions. These observations indicated a more comprehensive design approach was needed if future separators were to operate efficiently.

RESEARCH

Although many informal contacts have been made with agencies in the United States, only the contact in Washington State provided useful information. Information from other areas, such as Austin, Texas, showed a considerable interest in storm water quality, but oil and grease removal or even identification of oil and grease as a pollutant was missing.

The City of Seattle and the Washington State Department of Transportation have provided a variety of information that, although not directly applicable to the establishment of criteria, is valuable. The information included:

- details and specifications for a modified manhole with oil restrictor
- drawings of a sedimentation and grease trap for an I-90 bridge
- several documents and reports on sediment basins and ponds
- a 1968 report evaluating a highway grease trap
- details for concrete oil separators manufactured in the Seattle area

No specific design criteria for oil and grease separators, however, were provided by the contacted agencies.

A literature search for references to oil and grease separation and removal was performed in Anchorage using the University and Public libraries. Thirty-four initial references were found. A brief review of the material, however, showed that the subject of oil and grease removal from storm water has not been thoroughly investigated. Some work existed on the subjects of large scale oil and grease removal from water and, in part, this information was applicable to the small quantity removal found in urban storm water oil and grease separators.

OIL AND GREASE CONTENT

The literature indicates high enough levels of oil and grease in storm water discharges to be of concern for aquatic organisms. The reported distribution of hydrocarbons in storm water runoff range from 0.69 to 13.1 mg/l (Hoffman, et. al., 1982). The major factor influencing the hydrocarbon level is land use. Parking lots and commercial areas contribute 3 times the concentration of oil and grease as residential areas (Stenstrom et. al., 1984). Hydrocarbon contents from samples taken in Anchorage correspond to the ranges indicated in the literature.

Much of the oil is associated with sediment particles. In Warwick, R.I., test basin data indicates that hydrocarbons associated with the sediments represent between 83 and 93 percent of the total in the runoff. These figures compare favorably with other cited values that ranged between 89 and 96 percent (Hoffman, et. al., 1982).

The Anchorage tests do not include the proportion of the hydrocarbon content of sediments for the influent samples. Samples taken of sediments retained in the separators, however, show hydrocarbon values between 640 and 1,940 mg/kg (Municipality, 1987), indicating that sediments are an important consideration for oil and grease collection.

SEPARATION THEORY

Oil droplets in storm water may be considered to have horizontal and vertical velocity components. While the horizontal component may be further resolved into X and Y vectors, the example can be simplified by assuming that the horizontal component consists only of a "downstream" or X direction. The horizontal and vertical velocities are influenced by different forces and may be considered independent for the purposes of analysis.

The horizontal velocity of storm water entering an oil and grease separator facility are dependent upon the hydraulic characteristics of the inlet pipe. Based on a 10-year design storm the recommended design velocity for storm drain pipes has a range between 2.0 feet per second, 15.0 feet per second. Average design velocities for storm drain pipes in Anchorage typically range from 2.5 to 7.0 feet per second.

For a 2-year design storm the flow at most outfalls in Anchorage are subcritical. Such flows have low velocities and are described as streaming and tranquil; gravity plays a more important role than inertial forces. Mixing of stormwater is minimal and the pollutants in stormwater tend to be arranged by density into levels or strata with the sediments on the bottom and oil, grease and other light pollutants near the surface.

Given a subcritical flow, the vertical velocity of oil droplets may not be critical in the design criteria of oil and grease separators. Since the oil, grease and other floating pollutants enter the oil and grease separator facility near the water surface, the facility design must merely insure that these materials stay at or near the surface to insure proper collection. The facility operation should not introduce vertical velocities that might mix the pollutants found on various levels.

If oil floating on water is contained by a barrier, but the water is allowed past the oil by a submerged weir (such as a containment boom), at a sufficiently high velocity the water will capture oil droplets and carry them through the submerged weir. At a critical velocity, V_C, the oil droplets become entrained in the flowing water stream and are carried through the facility to the receiving waters. Therefore, the maximum design velocity for an oil and grease separator must be the critical velocity, V_C. The critical velocity has been investigated for containment of oil spills on large bodies of water with floating booms.

OIL BOOM PERFORMANCE

An oil boom floats on the water surface for the purpose of collecting and containing oil. Portions of the boom are designed to extend above and below the water surface to contain the oil. Treated water passes beneath the boom. According to oil containment technology, the following criteria for oil booms have been developed (Sitting, 1974):

1) the critical velocity V_C is 0.62 feet per second,
2) the depth of the boom into the water is between 2 and 3 feet, and
3) the distance in front of the boom in which the critical velocity must be maintained is approximately five times the boom depth beneath the water surface.

In an oil and grease separator, a baffle performs the same function as an oil boom, and oil boom criteria may be directly applied to the design.

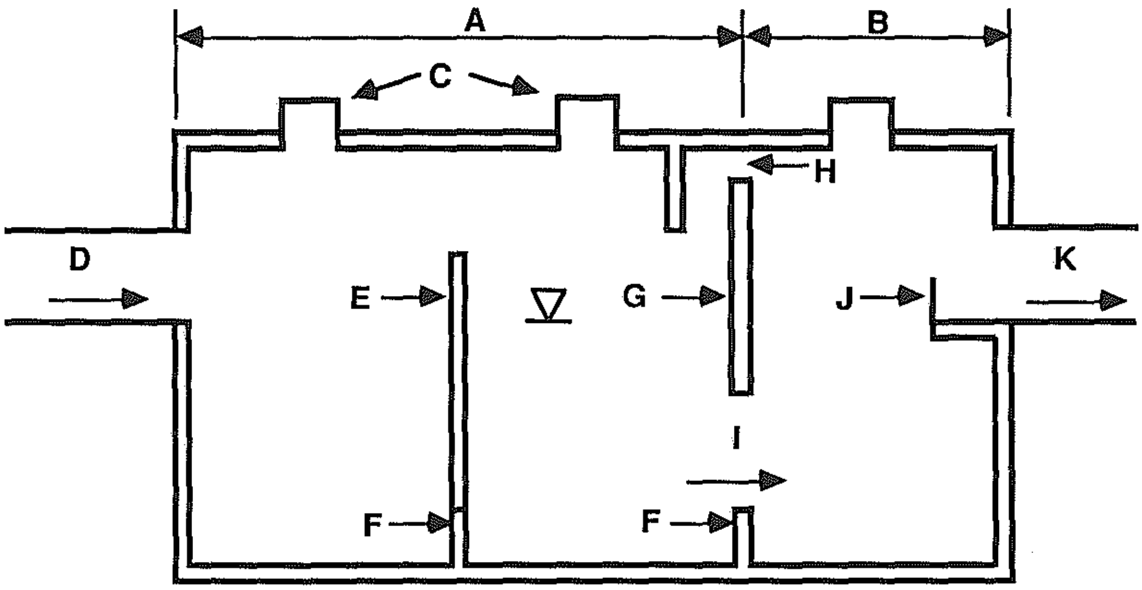
OTHER TECHNOLOGY

The literature also contains information on the use of parallel plate separators. In this type of separator the overflow rate, which is related to the horizontal projection of the plate area, determines the efficiency. Given the same overflow rate, both tilted parallel plate and perforated horizontal plate installations show similar performances (Zeevalkink, et. al., 1983). The time required to clean these facilities, including the need to remove sediments from beneath the plates, limits the application of this technology for storm drain outfalls in the Anchorage area.

Another approach described in the literature is the injection of air to float stable oil from emulsions. Experimental results show efficiencies between 50 and 99 percent (Van Ham, et. al., 1983). The application of this methodology is used in industrial applications where limited discharges and controlled flow rates allowed efficient treatment. Application to storm drain discharges appears to be cost prohibitive.

DESIGN CRITERIA

The oil and grease separator criteria developed as a result of the agency and literature information are provided below (Figure 2).



A: INLET CHAMBER
B: OUTLET CHAMBER
C: ACCESS PORT
D: INLET PIPE
E: ENERGY DISSIPATOR
F: SEDIMENT BAFFLE
G: SUBMERGED WEIR
H: OVERFLOW
I: WEIR OPEINING
J: OUTLET WEIR
K: OUTLET PIPE

FIGURE 2. New Style Oil and Grease Separator

<u>General:</u> An oil and grease separator consists of a collection chamber and an outlet chamber separated by a submerged weir.

Collection Chamber: The inlet pipe discharges into the collection chamber. The collection chamber reduces the stormwater velocity through an increase in the cross sectional flow area and, if necessary, with energy dissipaters. The stormwater velocity cannot exceed 0.62 feet per second for a distance in front of the weir equal to five times the weir depth beneath the water surface.

Outlet Chamber: The outlet chamber discharges into the outlet pipe.

Submerged Weir: The submerged weir extends above the expected high water level at least 0.5 feet. The weir extends below the low water level at least 2.0 feet.

Further criteria have been provided by the Department of Public Works as follows:

Design Storm Event: An oil and grease separator is to be designed using a 2-year storm event. The facility is designed to allow passage of the 10-year storm event.

The Municipality Street Maintenance Division has provided information relating to cleaning and maintaining oil and grease separators, and from the information provided, the following criteria has been developed:

Vehicle Access: Oil and grease separators must be vehicle accessible, preferably located in the street right-of-way.

Access Ports: Standard manhole frames and covers are to be used for access to the separator from the surface. Manhole access ports shall be located no further than four feet from a wall and shall be located every eight feet on center along the length and width of a separator.

Chamber Dimensions: To provide maintenance access, the minimum collection and outlet chamber length is four feet each, and the minimum facility width is four feet.

Facility Material: Oil and grease separators are to be constructed of portland cement concrete. The use of metal for plates and baffles shall be kept to a minimum.

Sediment Collection: Oil and grease separators will be constructed to retain fine sand and larger particles. Storage will be designed to insure that one year's accumulation of sediments can be retained without affecting the flow efficiency of the separator.

CLARK'S WAY APPLICATION

The first application of the previously stated criteria to a facility was the Clark's Way/Campbell Creek Oil and Grease Separator Project. In order to illustrate the application of the criteria to this project, the major design elements are discussed below.

Design Storms: A drainage study existed for the Clark's Way area. From this study the SAM (System Analysis Model) computer simulation provided an estimated 10-year peak flow value of 59.8 cubic feet per second (Municipality, 1981). Interpolation of a 2-year event from the 10-year flow value resulted in a design flow of 37.4 cubic feet per second for the separator.

Design Velocity: In order to be conservative, a ten percent reduction in the design velocity was made from 0.62 to 0.55 feet per second.

Cross Section Area and Dimensions: At the 2-year event peak, the required cross section area was computed by dividing the peak two year event flow by the design velocity; the result was 68 square feet. Due to the inlet pipe dimensions (a 40" x 66" arch pipe), the minimum facility width was approximately seven feet. In order to limit deep excavation during construction, a width of twelve feet was chosen; the required water depth, then, was computed to be 5.7 feet. During the peak 2-year event the storm water would be 1.4 feet deep in the inlet pipe and the resulting water depth below the inlet pipe invert would then be 4.3 feet.

Recognizing that large sediment particles will collect in the bottom of the facility, a 1.5 foot depth was selected for sediment storage. The depth was calculated by using the anticipated annual sediment load from the SAM computer simulation. The computed depth was doubled to account for uneven distribution across the bottom of the separator.

A final facility height of 11.5 feet was chosen with the following dimensional components:

head room	2.2 feet
pipe height	3.3 feet
water depth	4.5 feet (increased from 4.3)
sediment storage	1.5 feet
Total	11.5 feet

Sediment Baffles: The sediment baffle height was chosen to be 1.5 feet.

Weir Dimensions: The wall between the two chambers consisted of the following components: a top overflow, a weir plate or baffle, a weir opening, and a sediment baffle. The top overflow opening height was designed to accommodate the 10-year peak with a 50 percent safety factor, and was 1.5 feet.

The weir opening was designed to allow a 1.10 feet per second velocity during the 2-year event peak (twice the 0.55 feet per second design velocity). This velocity increase, and the following velocity decrease as the discharge enters the outlet chamber, was incorporated into the design to maximize the sediment removal characteristics of the separator.

The facility height of 11.5 feet determined the weir height. A summary of the component heights were as follows:

overflow	1.5 feet
weir	5.7 feet
weir opening	2.8 feet
sediment baffle	1.5 feet
Total	11.5 feet

Collection Chamber Length: During the 2-year event peak, the depth of the weir below the water surface was calculated to be 2.9 feet. The collection chamber length must be five times this depth or 14.5 feet.

Outlet Chamber Length: A weir was added to the outlet pipe to discourage short circuiting. The weir was placed on a shelf that extended two feet into the outlet chamber. Adding this two feet to the four foot minimum, yielded a six foot chamber length.

CONCLUSION

Urban storm water requires treatment to remove oil and grease to protect the environment and past design efforts overlooked basic factors in the separation process. To improve the treatment of storm runoff within the Anchorage area, the Municipality researched current literature and applied the collected information to the development of new design criteria for oil and grease separators.

The Clark's Way oil and grease separator was the first facility to be constructed using the new criteria. As a follow-up to the research effort, the Municipality recently initiated collection of field data at this site to test the new design parameters.

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STREAM RESTORATION DESIGN FOR A SMALL URBAN STREAM

by Larry A. Rundquist[1] and Thomas R. Bacon[2]

ABSTRACT

A reach of the South Fork of Little Campbell Creek in Anchorage, Alaska, that was turned into a ditch by area development, was selected to be restored back to a more natural configuration. The Municipality of Anchorage originally funded a small pilot project to investigate urban stream habitat improvement possibilities. Subsequent icing in the channel reduced the stream capacity and caused flooding of an adjacent schoolyard. The project scope was increased to address the flooding problem. The local residents were heavily involved in the design process and channel realignment was made possible after the Municipality acquired land from mobile home owners adjacent to the stream. In addition to providing channel improvements to control icing and flooding, the design included vegetation, channel meanders, and a pool and riffle sequence to provide fish habitat. The project showed that stream rehabilitation is possible in the constraints of an urban environment.

INTRODUCTION

A reach of the South Fork Little Campbell Creek originally had an irregular meandering configuration through an undeveloped area of Anchorage. Initial construction of an elementary school and platting of residential lots resulted in moving the stream from its natural alignment to the property lines in the form of a ditch. The design of stream restoration features for this reach of stream is the topic of this paper.

The background of the study reach is described briefly followed by a description of the procedures used in designing the new stream channel. The procedures presented in this paper can generally be used in the design of other urban stream restoration projects.

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2 Project Manager, Municipality of Anchorage, Department of Public Works, Box 196650, Anchorage, Alaska 99515-6650.

BACKGROUND

Project History

The design reach of stream was the South Fork of Little Campbell Creek in the vicinity of Abbott Loop Elementary School (Figure 1). Aerial photographs showed that the original meandering configuration of this stream was first changed prior to 1959, when construction of the Abbott Loop Elementary School pushed the lower end of the study reach into a 90 degree bend to make room for the school playground. The stream was altered again when it was pushed into a second 90 degree bend upstream of the first to allow construction of a mobile home park along Atkins Place. Little else was done at the site until 1982, when the Municipality of Anchorage Department of Public Works (DPW) excavated the channel deeper in the lower section and in 1986, when the Alaska Department of Fish and Game required placement of alternating rock dikes in the straight reach along the school yard fence to give the stream a slight meandering pattern.

The Municipality of Anchorage (MOA) identified this reach of stream for a small pilot project to investigate urban stream habitat improvement possibilities in 1985. Ott Water Engineers, Inc., was chosen to provide the necessary design services.

Icing in the stream channel during the winter of 1985-86 reduced the capacity of the channel and resulted in flooding of the school yard. Odor of the flooded water caused the Municipality to collect water quality samples; analyses indicated that the water was polluted by bacteria. The project scope was increased to address the flooding problem. A separate project explored the potential sources of pollution.

Project Objectives

Much of the stream reconstruction guidelines in the current literature stressed the study of natural meander patterns as a template for proposed improvements. This recommendation was based on the concept that a stream will seek a state of equilibrium that includes some degree of meandering and assumed that the stream will have sufficient land to attain a natural configuration.

Restoration of the natural stream pattern of the study reach was not possible because of the constraints of the surrounding urban development. After the stream was located along the property lines, the adjacent school and residential structures were constructed where the stream meanders and floodplain had been. This situation is typical for many stream sections in the Anchorage urban area.

Development in the historic floodplain also restricted the habitat features that could be incorporated into the project. Trees, fallen logs, and other vegetation in the natural floodplain provided fish and wildlife habitat and added hydraulic roughness to slow flood flow velocities. These same features in the urban setting, if not carefully designed,

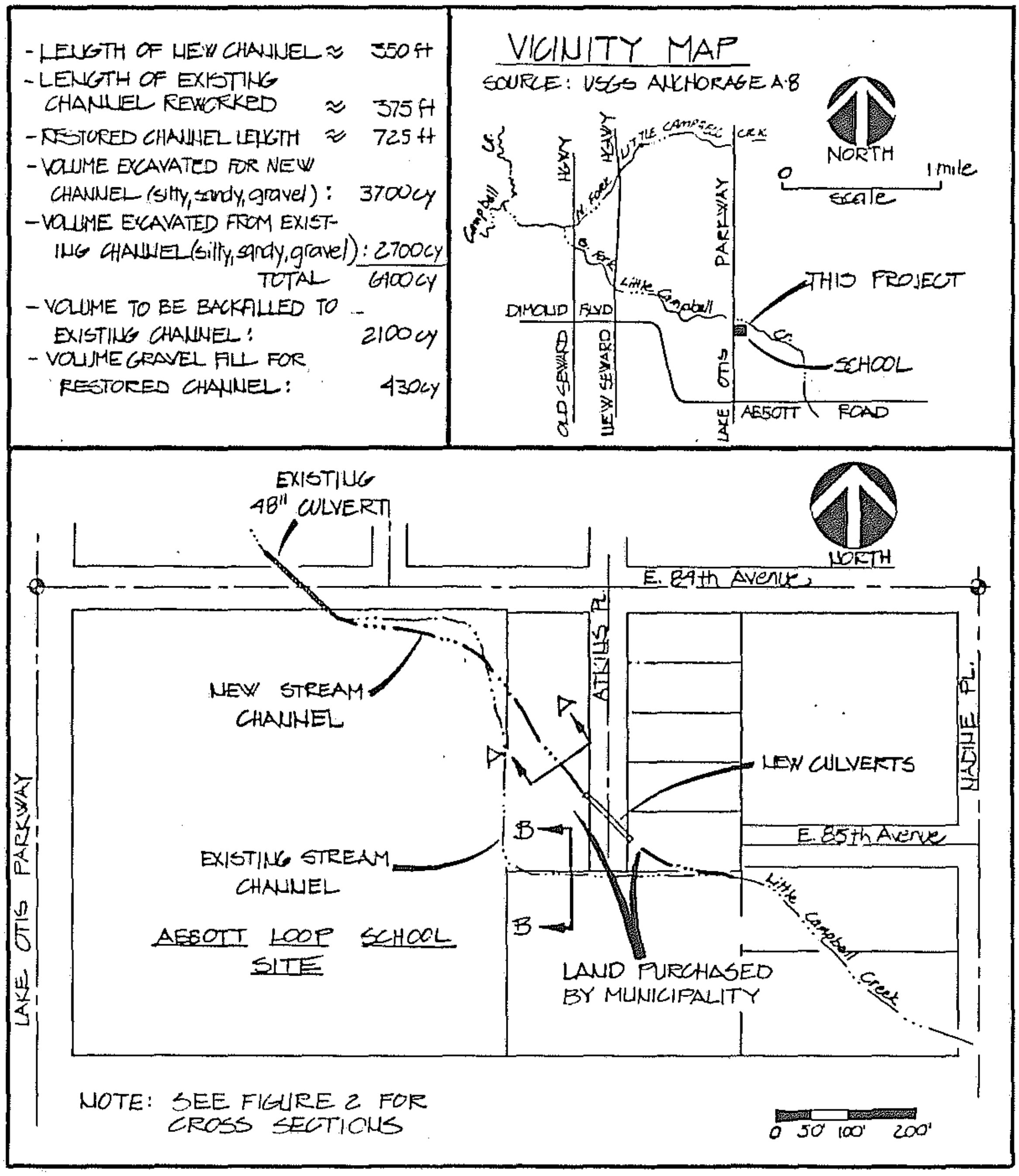

Figure 1. Location map for the stream restoration study reach.

became flow obstacles that extended the effective floodplain and resulted in damage to developed property.

The South Fork Little Campbell Creek improvements project was the Municipality of Anchorage's first attempt to reconstruct an urban stream. The overall project goal was to identify techniques and development strategies that can successfully recreate fish habitat within the constraints of the urban environment.

DESIGN PROCESS

Alternatives Evaluation

Six alternative channel configurations were identified by the project team headed by Ott Water Engineers and presented to the School District and local residents. The alternatives included straightening the stream by routing it through the school playground, increasing the radius of the sharp 90 degree bends, routing the stream through privately owned land, and collecting stream overflow and transporting it under the school playground in a culvert. Habitat improvements were included in all six alternative alignments.

Input to the selection of the alternative used in the design was solicited from the School District and from the general public at several public meetings. This input was used by a Mayor-appointed citizen advisory committee to select and refine the primary alternative. It was very apparent that soliciting input from the public resulted in a heightened public interest and cooperation in the project. Tenants in mobile homes agreed to move, and owners of the mobile home properties along Atkins Place agreed to sell their property and move their mobile homes to allow the project to continue.

Preliminary Design

The first step in the preliminary design process was to evaluate the hydrology of the stream at the project location. A 1984 restudy of the Flood Insurance Study for the stream by the U.S. Army Corps of Engineers (COE) had identified the 10-, 50-, 100-, and 500-year recurrence interval flows (Churchill, 1987). The 100-year flow for the stream was 155 cfs. Data measured by the U.S.Geological Survey at the mouth of the stream was adjusted for drainage basin size and compared with an extrapolated curve from the COE flood data to estimate the 2 year recurrence interval discharge to be 25 cfs. Typical summer flows of about 2 cfs were also estimated from the gage data at the mouth and from gage data on other streams in Anchorage.

The next step of the preliminary design was to select the channel alignment. While the conceptual alignment was selected in the alternatives evaluation phase of the project, selection of the specific alignment involved consideration of the following constraints and objectives:

- o Channel hydraulics
  - straighten channel to eliminate sharp bends
  - shorten stream length to increase gradient
- o Land ownership constraints
  - tie into stream alignment at project boundaries
  - minimize amount of school yard property utilized
- o Other considerations
  - reserve space for future amenities such as a bike path

The selection of the alignment defined the channel gradient, which was used with a roughness coefficient (0.040) in the Manning hydraulic equation to define a preliminary channel cross section. The criteria used in defining the cross section shape include (Figure 2):

- o A narrow and deep low water channel (6 ft top width by 2 ft depth)
  - to minimize potential for icing development
  - to provide increased depth cover for fish
  - to increase hydraulic efficiency at normal flow
- o A vegetated overbank riparian zone at about 2-yr flood level
  - to minimize scour potential of main channel during floods
  - to provide terrestrial habitat
  - to provide vegetative cover for fish
  - to provide filtering of overbank flow by vegetation
- o A second vegetated terrace level at about 20-yr flood level
  - to reduce flow velocities through additional spreading of flow
  - to provide a catch basin for upslope erosion debris
  - to provide a stable surface for revegetation efforts
  - to be used for occasional uses such as bike path
- o The constraint of present and proposed topography and land uses
  - to limit the height of the banks in areas with limited topographic relief
  - to limit the width of the channel in areas such as along E. 84th Avenue and the school yard fence

The preliminary cross sections were input to an HEC-2 hydraulic model of the stream reach, using existing information upstream and downstream of the study reach which had been developed by the COE for the restudy of the Flood Insurance Study. The hydraulic model was run to verify the selection of the cross section shapes and to develop downstream conditions for the design of the culvert to be placed under Atkins Place.

The design of the culvert followed a procedure developed by the COE for use in Flood Insurance Studies, in which the HEC-2 model was used to quantify the downstream conditions for a range of flows, a separate HEC-2 model was used to define the rating curve for weir overflow of the road embankment, and standard nomographs were used to define the rating curve

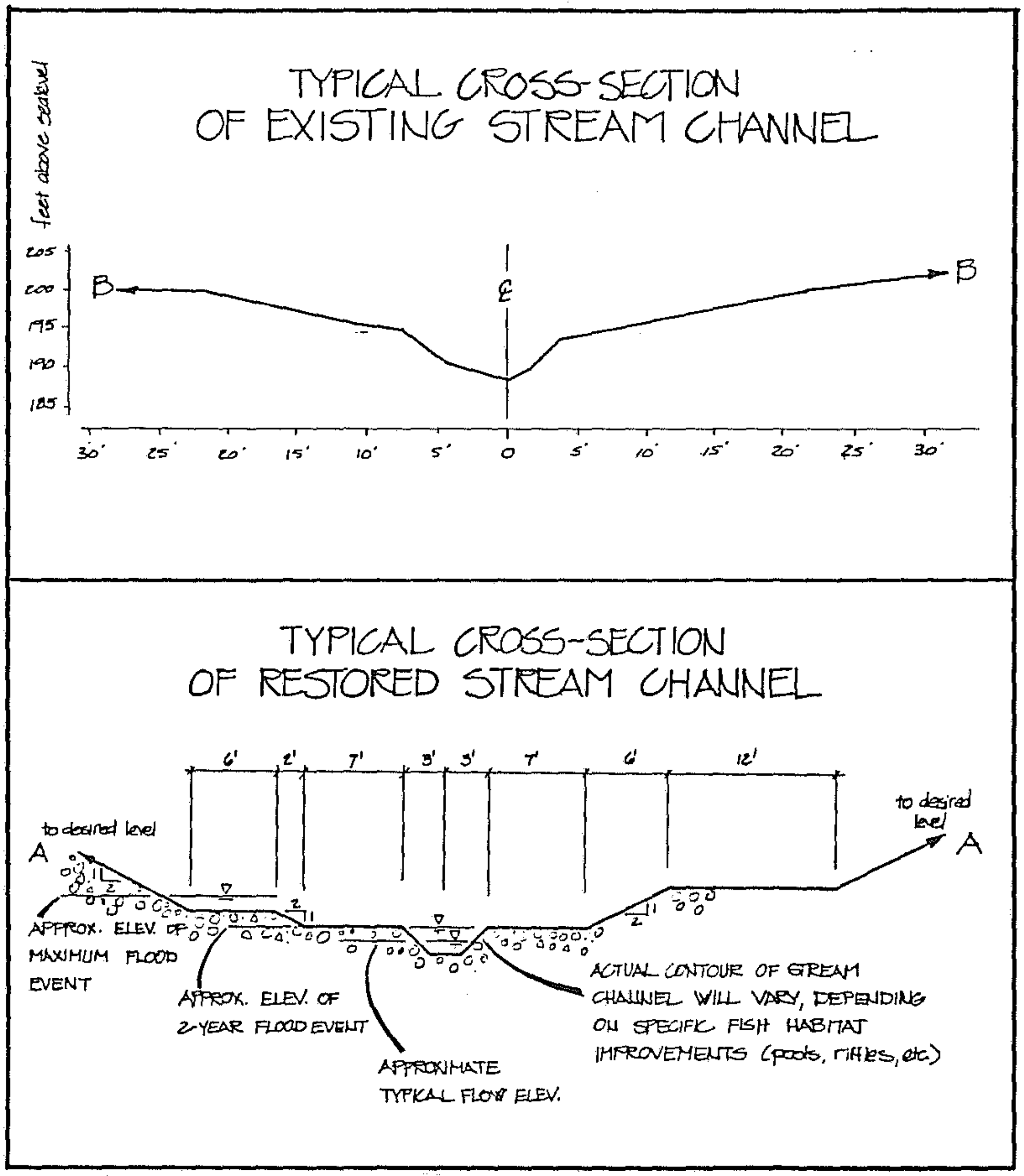

Figure 2. Typical existing and designed channel cross sections.

of the culverts. The rating curves were added graphically to define the rating curve of the culvert system.

The culvert system designed for the Atkins Place crossing included a main 4'-7" x 6'-1" x 60 foot long culvert with one foot of cobbles placed in the bottom and two 30" diameter circular culverts placed on either side and above the invert level of the main culvert. The inverts of the two 30" culverts were staggered at elevations one and two feet above the invert of the cobble substrate in the main culvert.

The set of three culverts was necessary to avoid raising the road level to provide the necessary cover for a larger main culvert. This allowed for an overflow section to be included in the design of the Atkins Place to accommodate excess flow during extreme floods (500-yr recurrence interval) or when the culverts are blocked without flooding adjacent properties.

Habitat features were then selected for inclusion into the design. A pool and riffle sequence was selected as a cost effective habitat feature that would also add diversity to the aesthetics of the stream reach (Figure 3). Each pool-riffle sequence was designed to have a length of 40 feet, which is 6.7 times the channel top width of 6 feet. A pool-riffle sequence is often 5-7 channel widths in length in natural conditions.

A slight meander pattern was designed by making each pool asymmetric with one bank steeper than the other, resulting in the deeper portion of the pool shifted off the centerline of the channel. Each riffle was aligned at a slight angle to the channel centerline to lead into the pool at the deepest portion of the pool. A row of boulders was placed at the tail of each pool (or head of each riffle) to control the level of the water in the pool and prevent scour.

Additional boulder groupings were included in the design along the riffle and in the heads of some pools to provide habitat diversity. The channel banks were designed to have variable density and diversity of vegetation to provide overhead cover and shade for fish and browse and cover for wildlife.

Approval of Preliminary Design

The preliminary design was provided to the DPW for comments and approval. DPW comments were incorporated into the design and the design was presented to the School District, Parks and Recreation Department, and permitting agencies such as the Corps of Engineers, Alaska Department of Fish and Game, and the Alaska Department of Environmental Conservation. Comments were evaluated and incorporated where applicable.

Final Design

The first step in the final design was to incorporate the ideas and comments of the reviewers of the preliminary design. The preparation of post-project topographic maps was the next step. This involved blending

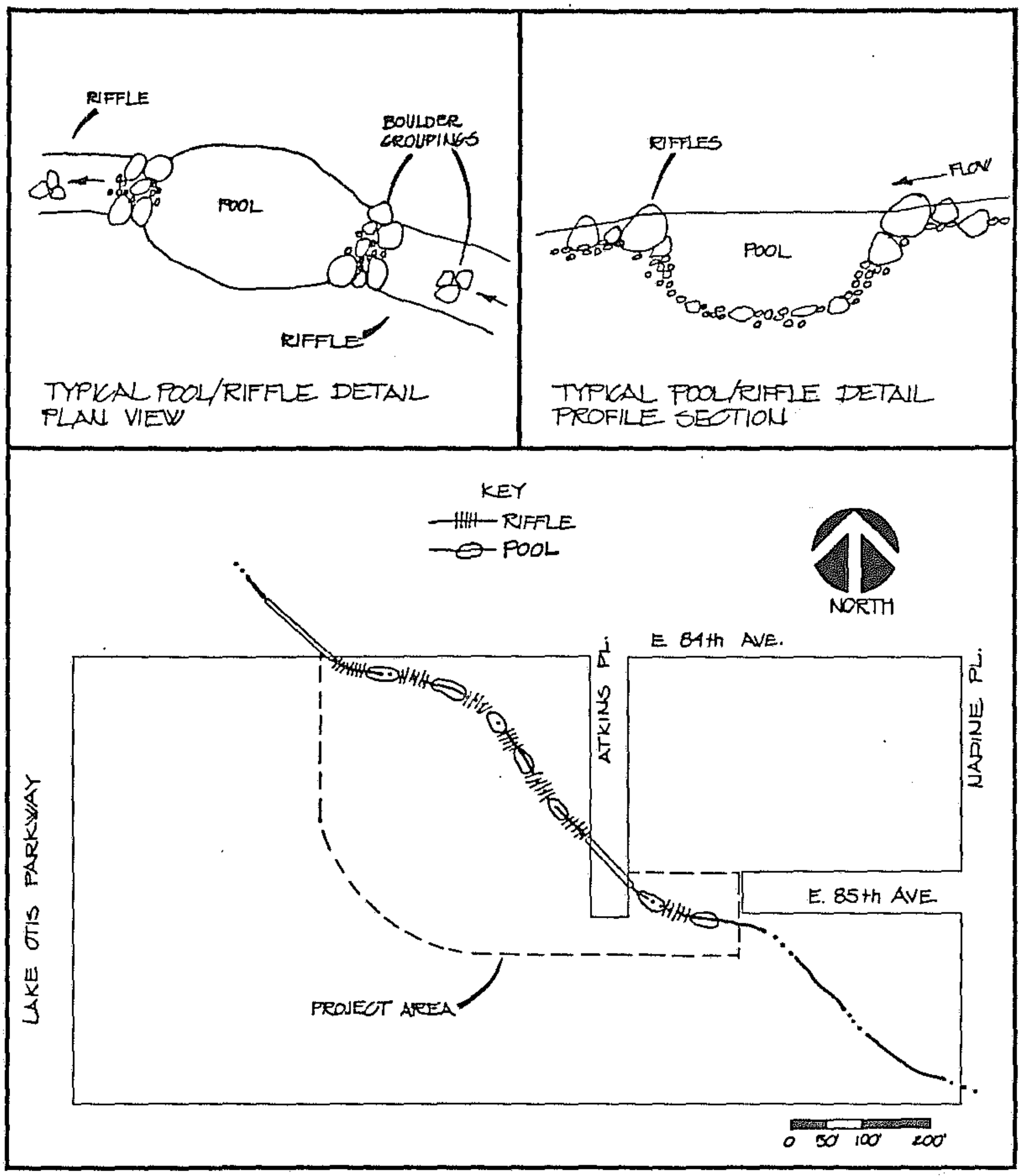

Figure 3. Typical design of pool and riffle habitat feature.

the preliminary stream channel design and the desired topographic features into the existing terrain. The desired topographic features include rolling terrain for diversity and low-lying terrain for flood control.

Once the topographic maps were available, they were used to check cross sections and run final hydraulic model computations and for development of the final revegetation plan. Construction details were also developed which include the method of stream diversion to minimize water quality impacts to the stream and the fate of the utilities in the abandoned mobile home lots. Construction details to minimize siltation include minimization of work in the active stream channel, pre-wetting the newly created channel, and gradual diversion of the stream into the new channel.

The final landscape plan was also completed. The plan, which was composed of native plant varieties, incorporated habitat values, esthetics, and the need to minimize future maintenance costs. Among the plants used for the project were varieties of willow, grasses, wild roses, and wild raspberries. Spruce and poplar trees were included in the plan for locations outside the channel area.

Permit Applications

Permit applications were filed with the Federal Emergency Management Administration (FEMA), U.S. Army Corps of Engineers (COE), Alaska Department of Fish and Game (ADF&G), and Alaska Coastal Management Program (ACMP). The application to the FEMA was for a Conditional Letter of Map Revision (LOMR), since redesign of the channel would require revision of the flood mapping for the area. Supporting this application were a short description of the project, a description of the hydraulic changes resulting from the project, a description of the topographic changes, a set of construction drawings, HEC-2 hydraulic model output, and topographic maps which delineated new flood limits and elevations.

The application to the COE was for a Section 404 permit for discharge of fill material into navigable waters. The ADF&G permit application was for a Title 16 permit for construction within an anadromous fish stream. A Coastal Project Questionnaire was completed and submitted to allow for a review of the consistency of the project with the Coastal Management Program. Each of these applications included a form supported by a description and sketches of the project. A 401 Certification for water quality was applied for from the Alaska Department of Environmental Conservation as part of the review process of the COE permit application.

SUMMARY

The MOA identified a reach of the South Fork of Little Campbell Creek for a small pilot project to investigate urban stream habitat improvement possibilities. Icing in the stream channel reduced the capacity of the channel and resulted in flooding of the Abbott Loop Elementary School play area; analyses indicated that the flood water was polluted by bacteria. The project scope was increased to address the flooding problem.

Various alternatives to solving the icing and flooding problems were identified and presented to local area residents. Solutions were constrained by the private property on both banks of the stream. Cooperation from local land owners in the form of selling their property allowed the project to proceed.

The sharp bends in the stream were eliminated and the stream gradient was steepened by shortening the reach length. Habitat features were included in the design in the form of pool-riffle sequences, rock groupings, and bank revegetation.

The steps of design and design criteria are listed as follows:

- Evaluation of alternatives
- Preliminary design
  - select channel alignment
  - select cross section configuration
  - design culverts
  - select habitat features
- Approval of preliminary design
- Final design
- Permit applications

While these steps are generally applicable to most projects, certain elements of this project were not typical of urban stream restoration projects. Specifically, the strong role of the Mayor-appointed citizen advisory committee, the cooperation of the tenants and owners of mobile home properties adjacent to the stream in moving from and selling the property to the Municipality, and the cooperation of the School District in allowing some of the play area to be used for the new stream alignment, provided more space for selecting a preferred alignment.

Many urban stream restoration projects will not have the benefit of ample space for selecting the new stream alignment and will be confined to an alignment which can not be changed. In such cases, many of the above steps can be used, but may need to be modified to fit the constraints at the site.

Other habitat features that were not included in this design, but should be evaluated in other designs include log undercut banks, riprap, tree cover, wing deflectors, submerged rock or log weirs, and rock islands (Babcock, 1982, Fisheries and Oceans, 1980, Rundquist, et al., 1986).

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INDEXING WATER QUALITY DATA ON SOUTHCENTRAL ALASKA LAKES

by Mary A. Maurer[1]

ABSTRACT

Published references to historical and current water quality data have been compiled in an index format on approximately 1000 southcentral Alaska lakes. The index includes clearwater, organic-stained, and glacial lakes grouped by regional and political boundaries. Lakes are located using 1:63,360 scale U.S. Geological Survey topographic quadrangles and latitude-longitude. References to limnological data for each lake are listed under the categories of morphometry, bathymetry, depth profiles, transparency, general chemistry, nutrient chemistry, and biology. A bibliographic section of all cited references is included. The index provides the sources of water quality data which can be used to identify and monitor cultural eutrophication in lakes.

INTRODUCTION

Lakeside residential development in southcentral Alaska has increased significantly in recent years. As a result, lake water quality can be degraded by urban runoff and domestic waste water from septic tank systems. This nutrient enrichment, known as cultural eutrophication, results in higher biological productivity and can produce dissolved oxygen depletion at depth, reduced lake transparency, noxious algae blooms, excessive aquatic macrophyte growth, and winter fish kills.

The Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys (DGGS) and the U.S. Geological Survey (USGS) recognized the potential for cultural eutrophication in southcentral Alaska and undertook a joint lake eutrophication project. One task of the project was to compile an index to the available historical and current water quality data (Maurer and Woods, 1987). The purpose of this paper is to describe the type of water quality information in the index and illustrate its use.

DATA ACQUISITION

Most of the published references cited in the index were obtained at public libraries or federal and state agencies. An effort was also made to include unpublished, in-house reports, sometimes referred to as "grey literature". The literature review included a search of the Water

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Resources Abstracts data base, the National Technical Information Service (NTIS) data base, and the Georef data base using the DIALOG Information Retrieval Service at the U.S. Department of Interior Alaska Resources Library. The DIALOG search produced 45 publications of which 13 were applicable to lake limnology in southcentral Alaska. As there are nearly 200 publications cited in the index, the DIALOG search confirmed the observation that most of the published data are in reports which are not specified as limnological (such as fishery and hydrologic reports), or are in reports which are not widely circulated.

Unpublished data in the USGS WATSTORE computer system were referenced in the index because these data are easily accessed. Unpublished data at Alaska Department of Fish and Game (ADFG) and Alaska Department of Environmental Conservation (ADEC) offices are not included in the index because the data are not in a computer system.

INDEX FORMAT

The index is divided into five geographic regions based on regional political boundaries: Municipality of Anchorage, Matanuska-Susitna Borough, Kenai Peninsula Borough, Kodiak Island Borough, and the unincorporated Copper River Valley and Prince William Sound area. Within a region each lake entry contains the following information: lake name designated as official or unofficial, location, type of data, and reference sources. Lake name is listed as official if it appears on USGS 1:63,360 series maps. Lakes are located by latitude and longitude coordinates and quadrangle.

The eight "types of data" categories are listed with specific examples of each type on Table 1. Each reference is cited by author and date next to the appropriate "type of data" category. When a lake is referred to by an obsolete or less commonly used name it is listed in the "comments" category. An example of a lake entry is shown in Table 2. A bibliography of all cited references is included as a separate section of the index.

FINDINGS

The index covers clearwater, organic-stained, and glacial lakes. They range in size from 1 acre to the 73,944 acre Tustamena Lake, but the majority are less than 500 acres. Of the nearly 1,000 lakes listed in the index, 330 are in the Kenai Peninsula Borough, 252 are in the Copper River Valley-Prince William Sound area, 220 are in the Matanuska-Susitna Borough, 147 are in the Kodiak Island Borough, and 43 are in the Municipality of Anchorage. Lakes in the Matanuska-Susitna Borough and the Municipality of Anchorage have more complete and abundant data coverage than the other regions. Generally, only 25 percent of the lakes in the index have bathymetric maps, water column profiles, transparency, general/nutrient chemistry, or biological data.

Table 1. Types of data in limnological index

Type of Data	Example
Morphometric	maximum water depth; mean water depth; volume; surface area
Bathymetric Map	
Water Column Profile	temperature; dissolved oxygen; pH; conductivity
Transparency	secchi disk; photosynthetically active radiation
General Chemistry	pH; dissolved oxygen; conductivity; hardness; cations and anions; metals
Nutrient Chemistry	nitrite-nitrate nitrogen; ammonia nitrogen; kjeldahl nitrogen; total phosphorus; orthophosphate
Biological:	
Bacteria	fecal coliform
Chlorophyll	
Phytoplankton	abundance; species list
Algal Growth Potential	
Phytoplankton Primary Productivity	
Zooplankton	abundance; species list
Aquatic Macrophytes	species list
Benthic Fauna	abundance; species list
Other Data	lake level; water temperature; water residence time; lake outlet discharge; earthquake effect; suspended sediment; morphoedaphic index
Comments	other lake names

Lakes that have either an extensive historical or current data are listed in Table 3. Karluk Lake has the most extensive historical data coverage with information dating from 1927.

INDEX APPLICATION

Two steps are required before data referenced in the index can be used to examine lake water quality. The first step is to determine

Table 2. Index listing for Sand Lake, Municipality of Anchorage.

LAKE NAME: Sand Lake

USGS OFFICIAL NAME: yes
LATITUDE - LONGITUDE: 61°09'06" 149°47'52"
QUADRANGLE: Anchorage A-8

TYPE OF DATA AND SOURCE

MORPHOMETRIC: ADFG (1986)

BATHYMETRIC MAP: Donaldson (1976); ADFG (1986)

WATER COLUMN PROFILES: USGS (1973a, 1976a, 1984); Donaldson and others (1975); Donaldson (1976)

GENERAL CHEMISTRY: WATSTORE (1967); USGS (1969, 1973a, 1973b, 1975, 1976a, 1984); Donaldson and others (1975); Donaldson (1976); ADFG (1976)

NUTRIENT CHEMISTRY: WATSTORE (1967); USGS (1969, 1973a, 1973b, 1975, 1976a); Donaldson and others (1975); Donaldson (1976)

BIOLOGICAL: Bacteria: USGS (1976a); Little (1985)
Chlorophyll and algal growth potential: USGS (1976a)

OTHER DATA: Lake levels: WATSTORE (1959-65, 1968-71, 1973-86); Zenone (1976)

Table 3. Lakes with extensive historical or current water quality data.

Kenai Peninsula Borough	Matanuska-Susitna Borough	Kodiak Island Borough	Municipality of Anchorage	Copper River Valley - Prince William Sound area
Bear	Big	Bare	Campbell	Dickey
Bradley	Finger	Catharine	Connors	Eyak
Crescent	Horseshoe	Dragonfly	Eklutna	Paxson
Grant	Johnson	Genivieve	Goose	Robe
Longmare	Junction	Island	Mirror	Summit
L.Salamatof	Knik	Karluk	Sand	Tangle
Packer Cr.	Lucille	Lee		Tokum
Short Pine	Matanuska			
	McLeod			
	Ravine			
	Reed			
	Seymour			
	Sliver			
	Tigger			
	Walby			
	Wasilla			

whether there are adequate data for the water quality variables of interest. The second step is to evaluate the data quality by examining the sampling and analytical methods used by the data collector. Then, for lakes that have a sufficient data base, the index can be used to: 1) examine temporal trends in water-quality variables, 2) identify lakes that show signs of cultural eutrophication, and 3) design a sampling program to define or verify cultural eutrophication.

An example of a lake in the index that addresses points 1 and 2 is Sand Lake, an urban lake in the Municipality of Anchorage which has both historical and recent dissolved oxygen profiles and water chemistry data (USGS 1973, 1984; Donaldson 1976) (see Table 2). The dissolved oxygen profile indicates a lower percentage of dissolved oxygen saturation in the summer hypolimnion in 1983 than in 1972 (Figure 1). In addition, index data show that specific conductance did not change appreciably between September 1968 (48 umhos) and August 1972 (52 umhos), but nearly doubled over a 11 year period with a measurement of 96 umhos in August 1983. It is apparent from these data that the lake is showing signs of cultural eutrophication.

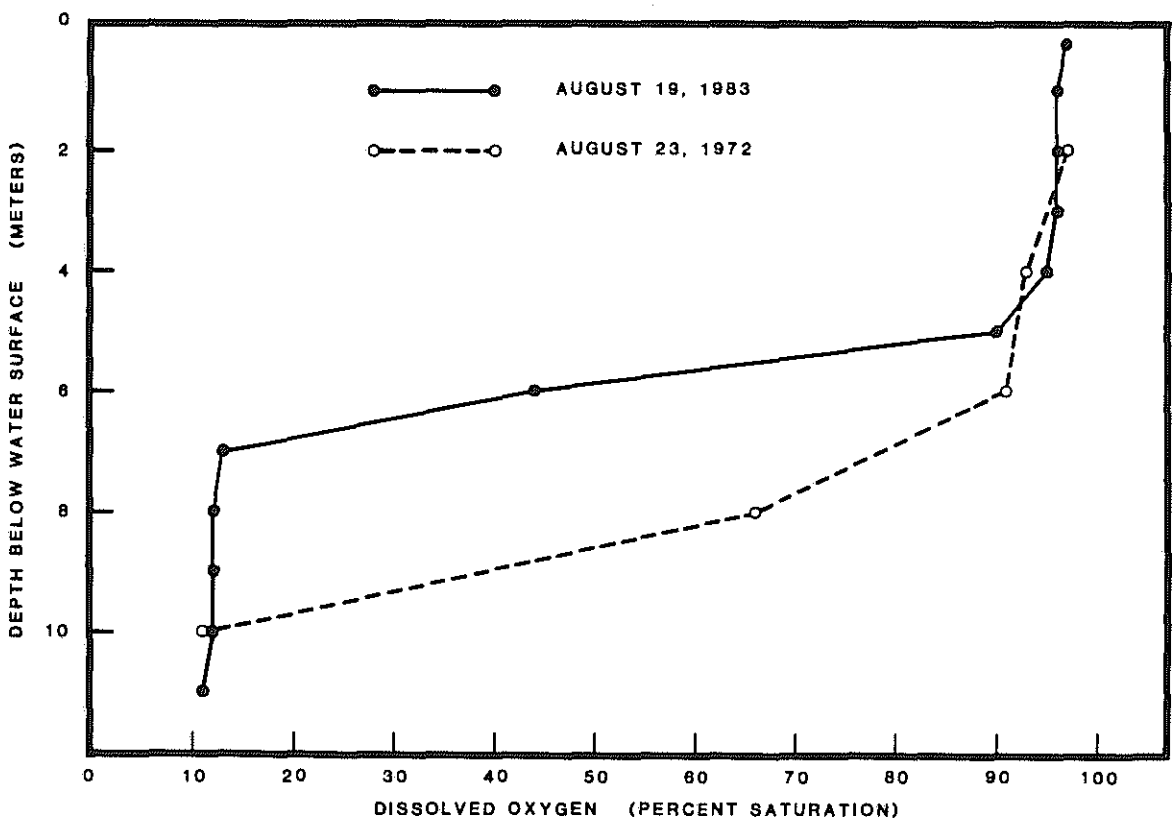

Figure 1. Temporal change in the dissolved oxygen profile of Sand Lake, Municipality of Anchorage. Source: USGS (1973, 1984).

CONCLUSION

The majority of lakes in the index do not have adequate historical or current water-quality data to document the progression of cultural eutrophication in Southcentral Alaska lakes. Approximately 5 percent of the lakes, particularly those in the Matanuska-Susitna Valley, have sufficient data to track trends in water-quality variables.

ACKNOWLEDGEMENTS

The author wishes to thank Stan Carrick of DGGS for reviewing the manuscript.

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SEASONAL VARIATION OF PHOTOSYNTHETICALLY ACTIVE RADIATION IN BIG LAKE, SOUTH-CENTRAL ALASKA

By Timothy G. Rowe[1]

ABSTRACT

The depth distribution of PAR (photosynthetically active radiation) was measured in Big Lake, south-central Alaska, during 1983-84 as part of a study of primary productivity. The quantity of PAR incident upon the lake surface was recorded hourly. A spherical quantum sensor measured the vertical distribution of PAR within the lake on a bi-weekly basis from May through October and on a monthly basis from November through April.

The PAR, in Einsteins per square meter per day, received daily at the lake surface varied with season and meteorological conditions; it ranged from 0.1 to 57.1 over the 2-year period. The depth distribution of PAR in the lake and the depth of euphotic zone were strongly affected by variations in incident PAR, by reflection from the lake surface, and by the extinction within the water column. In summer, about 5-10 percent of the incident PAR was reflected, whereas in the winter about 90 percent was reflected by a cover of snow and ice.

Extinction coefficients ranged from 0.30 to 0.67, with a slight tendency for the high values to occur during periods of water-column circulation. The depth of the euphotic zone ranged from 1.0 meter in the winter to 14.5 meters in summer.

INTRODUCTION

In the past few years the population of south-central Alaska has increased greatly. The increased residential development associated with this population growth has created concern about potential nutrient enrichment of the area's numerous lakes. Responding to such concerns, in 1983 the U.S. Geological Survey and the Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, initiated a cooperative study of the limnology and primary production of Big Lake. This 1,213-square-hectometer lake has extensive residential development along its 27-kilometer shoreline (fig. 1).

One of the main data requirements of a primary productivity study is the amount of solar radiation incident upon the lake surface and within the water column. Only a few studies have been done on solar radiation inputs to south-central Alaska. Branton and others (1972) collected 11 years of solar radiation data at Palmer, Alaska, and Coffin (1984) collected 2 years of solar radiation data at various locations near the Susitna River. Even fewer data are available on the distribution of solar radiation within the water column of Alaskan lakes, especially under ice conditions.

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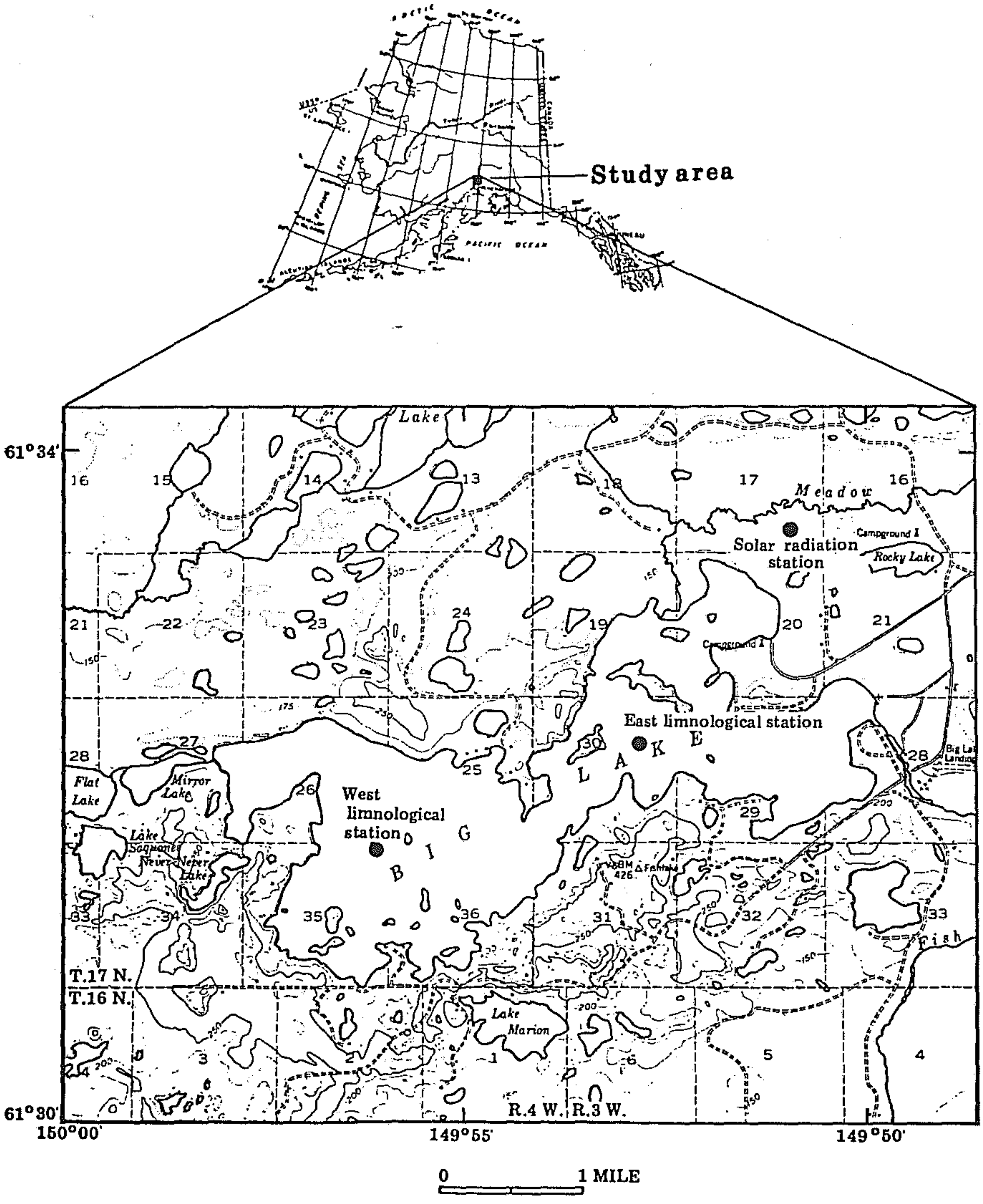

Figure 1.--Location of limnological sampling stations and solar radiation station at Big Lake.

The Big Lake study was designed to provide the limnological and solar radiation data required for input to a computer model that calculated the integral primary productivity of phytoplankton in Big Lake. The model requires solar radiation data, and coefficients for water-surface reflection and water-column extinction of radiation. These three variables largely determine the depth of the euphotic zone, the depth within which photosynthesis exceeds respiration. This paper discusses the seasonal variations in solar radiation, of reflection and extinction, and the depth of the euphotic zone at two limnological stations on Big Lake over a 2-year period from January 1983 through December 1984.

METHODS

The radiation data were recorded as photosynthetically active radiation (PAR), which is the portion of the spectrum ranging from 390-710 nanometers (Vollenweider, 1974). The PAR incident upon the surface of Big Lake was collected hourly using a recording solar monitor equipped with a quantum sensor designed to detect only PAR. This sensor was located just northeast of Big Lake, at the Alaska Department of Fish and Game's fish hatchery (fig. 1).

Profiles of PAR within the water column were obtained at two limnological stations designated East and West (fig. 1), on either a biweekly basis (May through October) or a monthly basis (November through April). Two types of underwater sensors were used to measure in-situ PAR. A planar quantum sensor measured downwelling radiation only, and a spherical quantum sensor measured the total radiation available in-situ. The spherical quantum sensor provides a more realistic measurement of in-situ radiation impinging upon phytoplankton than does the planar sensor.

The water-column profiles consist of data recorded at 1-meter intervals, from 1 meter below the water surface to a depth at which the PAR was less than 1 percent of that incident upon the water surface. The profiles were started at the 1-meter depth to avoid errors caused by wave action (Williams and others, 1980).

The sensors were lowered by cable using a 2.5-meter boom to reduce interference due to boat shadow. In-situ PAR measurements under ice and snow cover were made through holes drilled by a gas-powered ice auger. Caution was taken as to disturb the snow and ice cover as little as possible. A semi-transparent plexiglass plate was placed over the drilled hole and snow was piled on top to simulate the existing ice and snow cover. Winter profiles were measured at 0.5-meter intervals, starting at 0.5 meters below the ice.

Radiation profiles were always taken in mid to late morning. This time period provides the best solar angle, which then gives better profile readings and less error (Shearer and others, 1985). The choice of which site to sample first was always randomly chosen to minimize bias. Details of the methods listed above can be found in a manual prepared by Shearer and others (1985).

The Beer-Lambert Law (Lind, 1979), illustrates the use of the PAR data to compute extinction and reflection coefficients. The equation is:

$$I_z = (I_o)e^{-nz} \qquad (1)$$

where I_z is PAR reading at depth z,

I_o is PAR reading at lake surface,

z is depth, in meters, below the surface of the water,

n is extinction coefficient, and

e is base of natural logarithms.

The extinction coefficient (n) is the slope of the line described by equation 1. Using equation 1, the PAR reading immediately beneath the lake surface can be determined; recall that this value cannot be measured directly because of wave action. The reflection coefficient is calculated by dividing the surface PAR value (I_o) by the calculated value of PAR immediately below the lake surface. The depth of the euphotic zone is defined here as the depth at which PAR incident upon the lake surface has been reduced to 1.0 percent.

RESULTS AND DISCUSSION

A histogram of the monthly input of PAR at Big Lake in 1983 and 1984 shows that the highest values in both years occurred during June (fig. 2). The seasonal variation of the PAR measured at Big Lake corresponds with that obtained by Branton and others (1972) at Palmer and also by Coffin (1984) for the Susitna River area.

The effect of meteorological conditions on daily amounts of PAR at Big Lake was often pronounced. For example, in June 1984, one day was completely clear, but the next day was totally cloudy. The PAR, in Einsteins per square meter per day, varied from 47.9 on the clear day to 17.6 on the cloudy day.

A comparison of the hourly PAR for the summer solstice (June 21) and winter solstice (December 21) is shown in figure 3. At summer solstice, the lake received 55.8 Einsteins per square meter PAR during its 20 hours daylength, with a peak hourly rate of 5.8 Einsteins per square meter. The 6-hour daylength on the winter solstice provided a daily total PAR of 0.9 Einsteins per square meter and a peak hourly rate of 0.3 Einsteins per square meter.

The ranges and mean values of surface PAR, extinction coefficients, and the depth of the euphotic zone at both limnological stations are listed in table 1. The data are shown for each station for open water and under ice. The results in table 1 were based on data measured by the spherical quantum sensor. The values for the planar and spherical sensors were similar, but the spherical sensor always read slightly higher than the planar sensor.

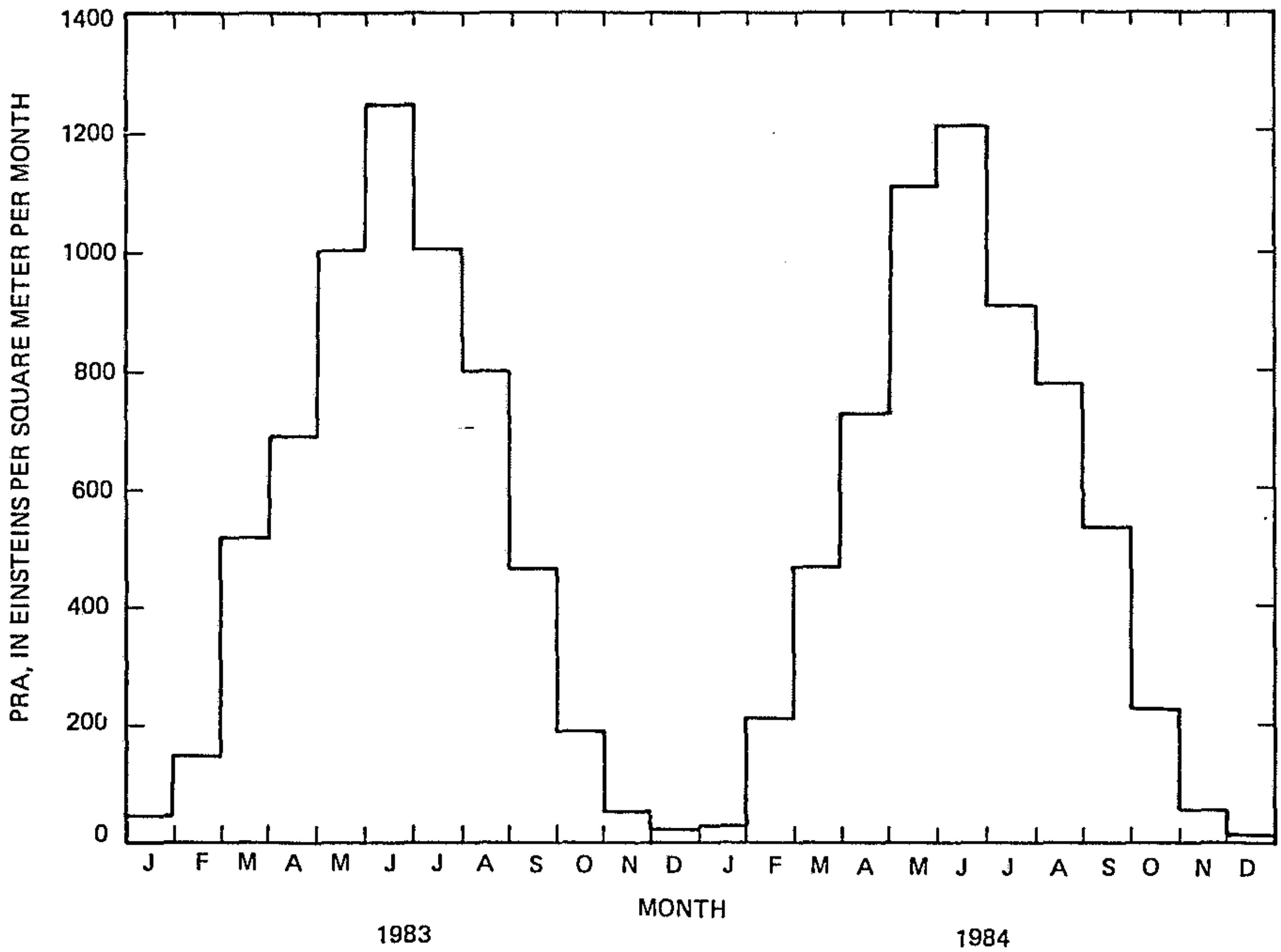

Figure 2.--Monthly input of photosynthetically active radiation (PAR) at Big Lake during 1983-84.

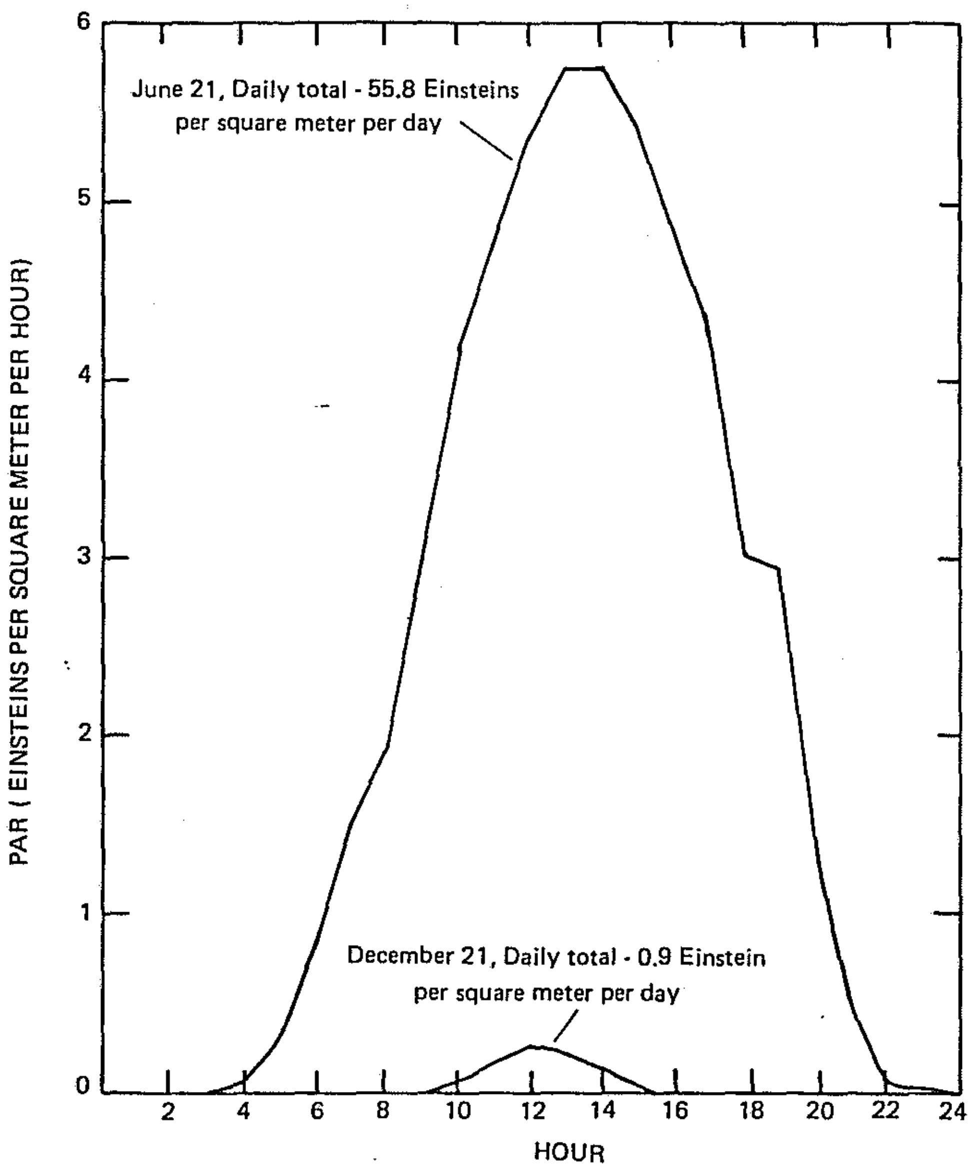

Figure 3.--Hourly input of photosynthetically active radiation (PAR) during summer and winter solstices of 1983 at Big Lake.

TABLE 1. Mean values and ranges of extinction coefficients, euphotic zone depths, and photosynthetically active radiation (PAR) at two limnological stations on Big Lake, 1983-84.

	West station				East station			
	Under ice		Open water		Under ice		Open water	
Variable	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Extinction coefficient per meter	0.40	0.30-0.65	0.38	0.32-0.50	0.44	0.30-0.62	0.48	0.37-0.67
Euphotic-zone depth (meters)	5.6	2.2-10.0	12.5	9.0-14.5	4.6	1.0-7.5	9.7	7.0-11.0
Surface PAR (micro-Einsteins per square meter per second)	426	17.8-1034	746	201-1373	422	19.2-1124	580	82-1301
Ice thickness, (meters)	.62	.30-.90	--	--	.71	.40-.90	--	--
Snow depth (meters)	.09	0-.30	--	--	.08	0-.25	--	--
Number of visits per year	9		20		9		21	

The West limnological station had slightly lower extinction coefficients and a deeper euphotic zone than did the East station. Although trends in data at both stations were similar, the following discussion pertains mainly to data collected at the West station, the deeper of the two.

In-situ PAR profiles were plotted for midsummer (July 2) and midwinter (February 29) 1984 on figure 4. A major difference between the winter and summer profiles was the depth of the euphotic zone, which varied from 14.5 meters in the summer to 2.2 meters in the winter. Reflection coefficients also varied greatly between summer and winter. In the summer about 5 to 10 percent of the solar radiation was reflected, but in the winter from 85 to 95 percent of it was reflected. A layer of older snow and ice reflected the most solar radiation, whereas the least was reflected from calm, open water. These results agree with studies on reflection in Canadian lakes (Roulet and Adams, 1984).

The extinction coefficients and the depths of the euphotic zone at the West station over the 2-year period are plotted in figure 5. Periods of snow and ice cover are also shown. The depth of the euphotic zone varied seasonally. Extinction coefficients ranged from 0.30 to 0.67 and showed a slight tendency for the higher values to occur during periods of water-column circulation.

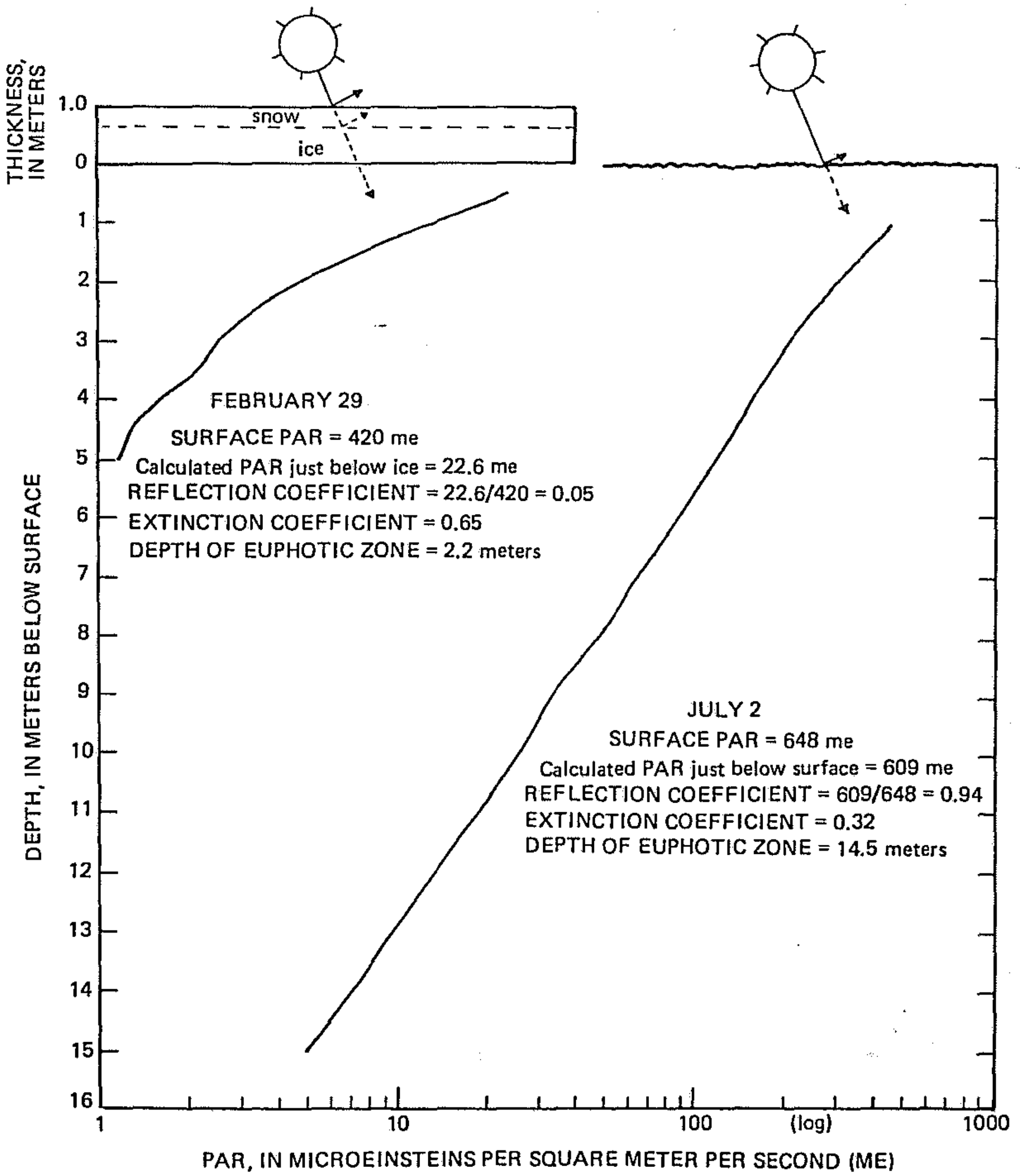

Figure 4.--In-situ photosynthetically active radiation (PAR) profiles, February 29 and July 2, 1984, West station, Big Lake.

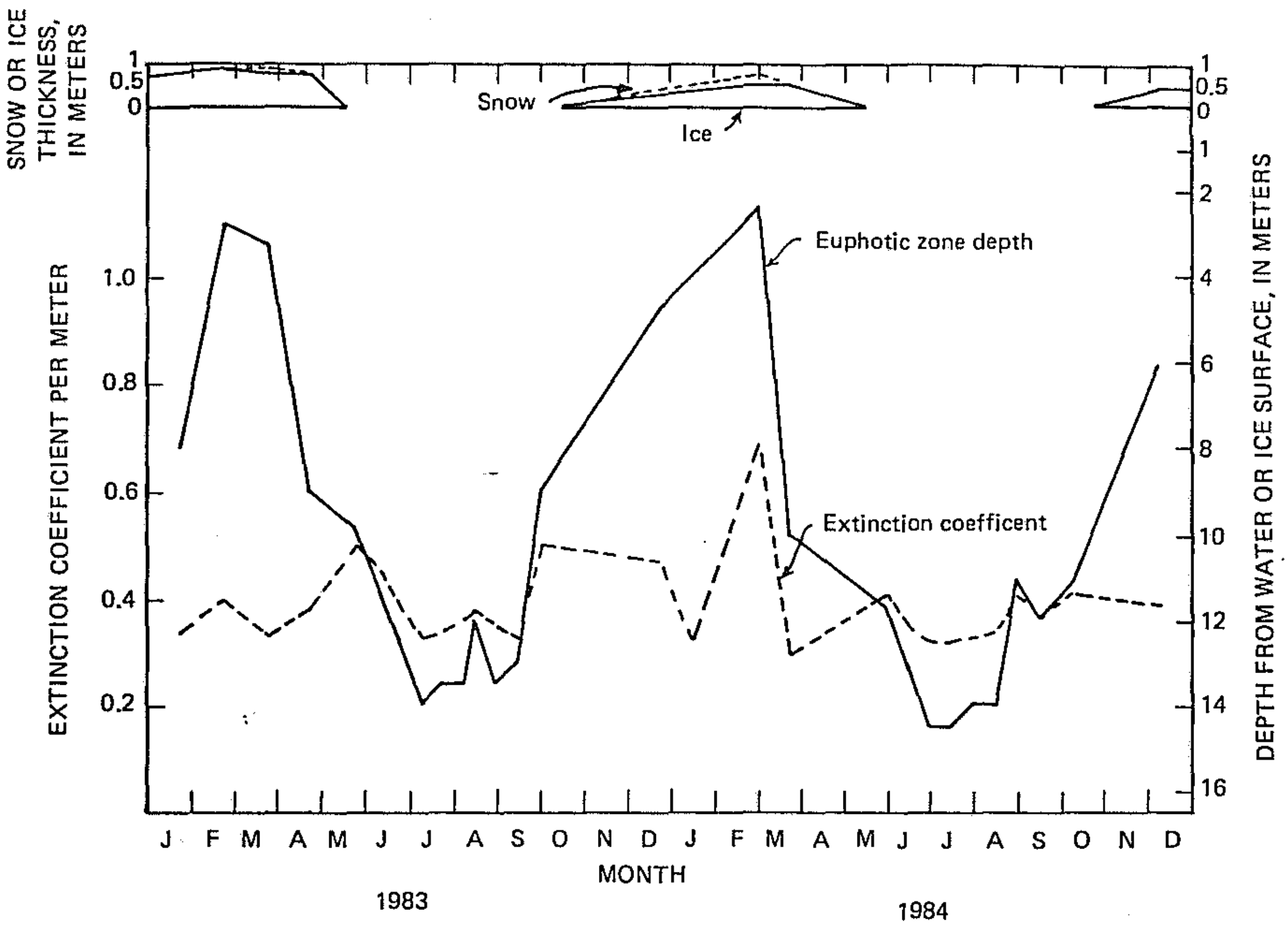

Figure 5.--Seasonal variation of extinction coefficients and euphotic zone depths during 1983-84, West station, Big Lake.

GROUNDWATER ISSUES

INJECTION WELL ACTIVITIES IN THE EASTERN OPERATING AREA OF PRUDHOE BAY

by Roderick W. Hoffman
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ABSTRACT

Injection wells are necessary to operate North Slope oil fields for several different processes. Gas has been injected to maintain oil reservoir pressure and store the gas since production commenced. Produced waters are reinjected to prevent surface contamination. Enhanced oil recovery with waterflood and miscible injectant takes place by injection. A permit for industrial and hazardous waste injection at Prudhoe Bay is pending.

The Prudhoe Bay area is an ideal injection site since there are no underground sources of drinking water, subsurface characteristics and well technology are well established, and no potential for public exposure exists. If authorized hazardous waste injection would have been less than 0.00006% of the total fluid injected and would not have consisted of any acutely hazardous waste. Despite these facts, the application for a hazardous waste injection permit has been controversial, and been in processing for more than two years. Additional regulatory programs connected with hazardous waste operations would take up to 3 years more to complete. Based upon the changing, complex, overlapping regulatory requirements and long-term waste disposal liabilities, current plans to inject hazardous waste have been abandoned.

INTRODUCTION

On December 21, 1984, ARCO Alaska, Inc., (AAI) submitted applications to the Environmental Protection Agency for permits to inject industrial and hazardous waste at the Oily Waste Injection Facility (OWIF) at Prudhoe Bay. EPA issued a public notice of draft Underground Injection Control (UIC) permits on October 2, 1986. These permits would not allow injection of "hazardous waste" (h.w.) until a second approval under the Resource Conservation and Recovery Act (RCRA) was obtained.

The draft permits resulted in numerous newspaper articles and considerable interest. The comments and articles indicated considerable environmental group concern and confusion over AAI's request. This paper discusses hazardous waste injection concerns expressed by newspapers and environmental groups in light of the extensive knowledge of injection wells used by the oil and gas industry as well as AAI experience with hazardous waste liability and regulatory issues.

The Waste Injection Controversy

Underground injection of waste started in the oil fields in the 1930s as an alternative to surface disposal of produced brines (salt water produced with the oil and gas). Disposal of wastes through injection wells began in the 1950s for other industries. Injection was considered a method to isolate wastes from the accessible environment by placing them into deep formations where they would remain for geologic time.

The principle of waste injection is based upon a simple observation that if the subsurface environment could adequately store quantities of oil and gas for millions of years, it could also adequately store waste. The engineering technology of injection wells is based on oil industry technology for well design, construction and operation. The geological principles applied to determine how and where to inject waste are also directly related to oil field reservoir geology and engineering knowledge. Several underground injection processes are used in oil fields to store natural gas and to recover more oil from subsurface reservoirs by injecting water into the oil producing formation (waterflooding) or other enhanced oil recovery methods.

Suitable injection sites have characteristics similar to subsurface areas which would trap oil and gas if hydrocarbons were present. Such sites require confining zones of thicker, less permeable rock which prevent vertical migration of the waste. Between the confining zones, a more permeable injection zone is needed. The injection zone should not contain potable water or other resources.

Injection of h.w. became controversial in the 1980s. Reports by the Natural Resources Defense Council (NRDC) (Gordon and Bloom, undated) and Citizens Clearinghouse for Hazardous Waste (August, 1985), alleged major well failures had occurred and groundwater contamination had resulted.

Subsequent reports have refuted the allegations made by NRDC (EPA, (May 1985), Michigan Department of Natural Resources, (May, 1986) Illinois Department of Energy and Natural Resources (Brower et al., 1986) and CH_2M Hill (April, 1986)). EPA found hazardous waste wells existed at 112 facilities across the United States.

Ninety of the facilities were still injecting waste through a total of 195 wells in 1984. Of all cases, only nine had problems which could have contaminated groundwater. In only four cases, groundwater contamination had actually resulted. These nine problem cases had occurred before a new regulatory program requiring more restrictive siting, operating and monitoring conditions was promulgated in 1984.

The rate of well failure resulting in contamination before the new regulations was 2.0%. Given that h.w. injection wells handle 60% of the h.w. produced in the U.S., this is a remarkable low contamination rate.

Regulatory Permitting History

Operation of the OWIF disposal wells has been previously authorized by State and Federal regulatory agencies. Alaska Department of Environmental Conservation (ADEC) issued wastewater disposal permits for produced water and non-hazardous waste injection at the OWIF.

Under the requirements of new 1984 regulations, AAI applied to EPA for a Class II injection permit (Class II wells are used to inject oilfield waste such as produced waters) on June 29, 1984, and for a Class I hazardous waste injection permit on December 21, 1984. The Class II permit under EPA was issued September 14, 1984. On June 9, 1986, the Class II program was acquired by the Alaska Oil and Gas Conservation Commission (AOGCC). AAI received authorization to conduct Class II injection activity from AOGCC on July 11, 1986. Since, 1980, EPA/ADEC has inspected the facility on an annual basis. Reports of the types and quantities of materials injected have been submitted routinely to the agencies for their review.

It took almost two years for the EPA to issue a draft Class I non hazardous UIC permit. Issuance of the h.w. authorization to the UIC permit is dependent on determining corrective action requirements for any facility solid waste management unit (SWMU) as authorized by the 1984 amendements to RCRA. Determination of appropriate SWMU corrective actions has been delayed by drafts of the revised State Solid Waste Regulations which regulate many of the same units. In addition, recently issued draft State regulations on siting of Hazardous Waste Management Facilities will require additional State authorizations. A reasonable case projection for obtaining all required authorizations would be 5 years from initial permit application. Facing this long and uncertain permitting process, on September 24, 1987 AAI decided to abandon plans to obtain authorization for injection of hazardous waste.

Injection Activities on the North Slope

Waste injection is only one of several types of injection activities on the North Slope.

The Prudhoe Bay Unit has over 4 billion dollars invested in gas handling and waterflooding facilities which are dependent upon injection technology. Injection technology is critical to the successful reinjection of natural gas produced with the oil, disposal of water produced with the oil, and waterflooding to extract more oil from reservoir.

Gas is injected through 18 injection wells. Over four trillion cubic feet (cf) of gas has been injected through these wells without any environmental damage or significant mishap. On a daily basis, approximately 2.6 billion cf (equivalent to about 463,000,000 bbl of gas at standard temperatures and pressure), are injected daily.

Produced water is separated from the oil stream and injected through six wells in Prudhoe Bay. Currently 557,000 bbls of produced water are injected daily. These wells have been in operation since 1978 without causing any environmental damage or having significant problems.

In 1984 waterflooding began in Prudhoe Bay. This process entails treating and then injecting seawater into the oil reservoir to recover more oil. More than 60 wells are being used for waterflooding and approximately 1,000,000 bbls of seawater per day are injected. Another enhanced oil recovery project is also taking place at Prudhoe Bay. This project, entailing injection of miscible gas, will inject about 50,000,000 bbl per day. Table 1 summarizes these injected volumes. Figure 1 depicts the depth and geological strata the various types of wells inject into.

TABLE 1

Comparison of Injected Volumes

Process	Daily Volume (bbl)
Gas Injection*	463,000,000
Water Flood	1,000,000
Miscible injectant*	50,000,000
Produced water	557,000
Oilfield Waste	500
Hazardous Waste**	0.1

*gas reported as bbl at standard temperature and pressure for comparitive purposes.

**Hazardous waste is not currently injected. The amounts are estimated based on amount currently generated.

Injection Technology

Injection technology is well established and has an exceptional record on the North Slope. Injection wells and production wells have the same fundamental design. Basically, wells consist of an injection tubing suspended inside a large casing (see Figure 2). The space between the tubing and casing is called the annulus. At the top of the well, the tubing and casing are joined by the wellhead. At the bottom of the well, they are connected by a packer. The casing is cemented to the surrounding rock. On the North Slope, the annulus is filled with a non-freezing liquid. Near the surface, additional outer casing is also included. (Variations of this basic scheme exist but are minor compared to the basic design).

The only subsurface leakage that can occur would take place through the tubing, packer and/or casing. The well design allows monitoring of each of these areas to assure there is no leakage. Any leakage from the tubing above the packer would be detected as an increase in pressure and/or fluid volume in the annulus. Leaking from the casing and/or packer would be detected by a loss of fluid volume or pressure in the annulus. Periodic pressure testing of the annulus also detects any weak points which may not have yet leaked. Repairs can be made if a leak is found. (U. S. E.P.A., 1977)

Confining Zones

The confining zone is that layer of rock or strata above the injection interval which prevents the injected fluid from escaping. All oil and gas fields have confining zones. These lower permeability zones typically consist of more consolidated, finer grained materials than the injection zone, thereby preventing fluid movement through them.

The OWIF disposal wells inject into the upper part of the Tertiary Sagavanirktok Formations. It is overlain by about 1900 feet of permafrost. This permafrost is saturated, making it act like a large block of dirty ice. Within the

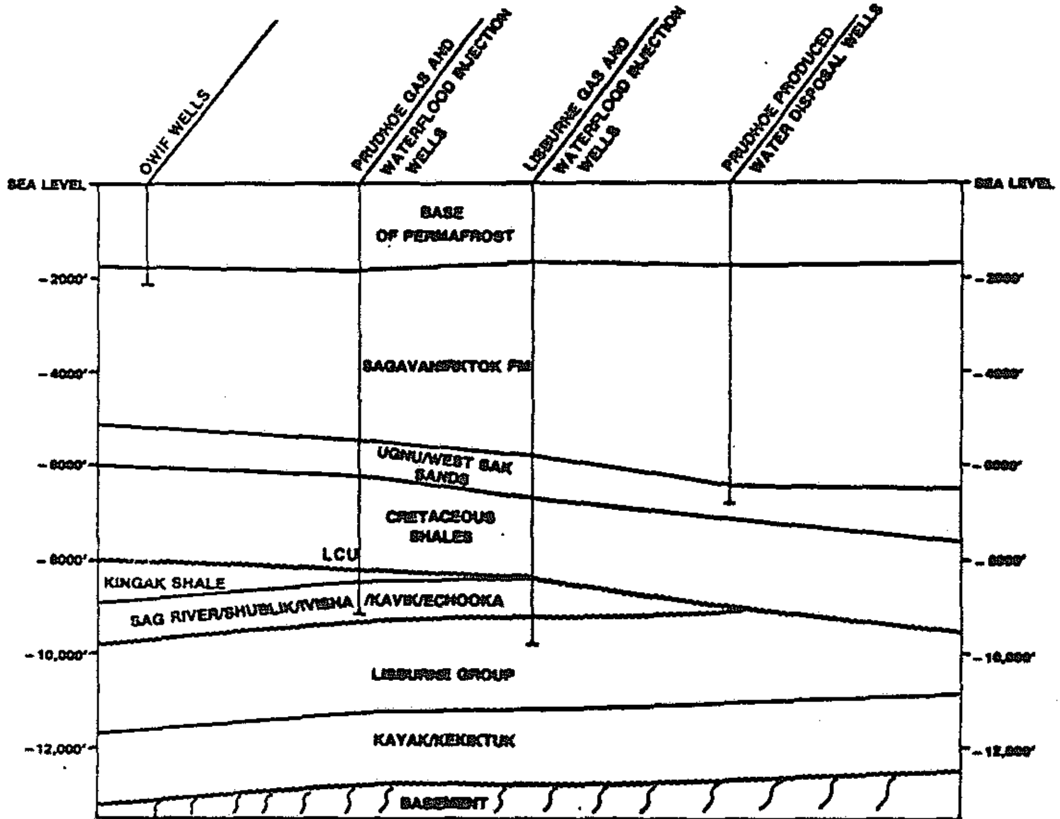

Figure 1

Geological Crosssection With Injection Well Depths

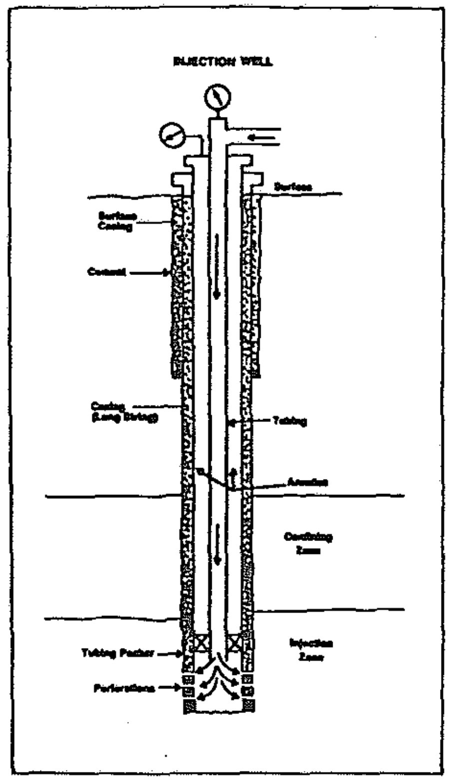

Figure 2

permafrost are layers which would act as confining zones even without being frozen. The permafrost has existed for tens of thousands of years. Its ability to act as a confining zone is shown by its ability to trap gas hydrates below it. Each of the other injection processes has other deeper confining zones.

Underground Sources of Drinking Water

In the EOA of Prudhoe Bay, there is no underground source of drinking water. The salinity of water at the OWIF injection wells is in excess of 12,000 ppm TDS. This means there is no way injected fluids can damage any underground drinking water resource-none exist.

Injected Fluids

A breakdown of waste volumes injected at the OWIF from October 1983, to May of 1985, showed crude oil, crude/diesel, and contaminated crude were the largest categories of waste, followed by diesel/water and brine/water mixes. (The Ad Hoc Task Group Addressing Liquid Waste Disposal on the North Slope, 1986). These wastes are produced from working on wells and production equipment and are exempt from hazardous waste regulations under RCRA. (Their disposal is regulated by AOGCC, ADEC and EPA under other laws)

Since August, 1985, the amount of waste oil injected has diminished due to increased recycling. Presently AAI recycles approximately 12,000 bbl of oilfield waste oil per month. Additionally, mixtures of gasoline, solvents, diesel, lab wastes and shop waste which are hazardous waste are no longer injected.

With the exception of acid, none of these waste are reactive with the subsurface fluids or formations. No reactions would occur that could generate heat to "melt" the permafrost and no gas producing reactions would occur. Measurements show that the base of the permafrost is the same depth now as when the wells were drilled in 1973.

The acids injected are spent fracture acids used in working over production wells. These are non oxidizing acids which will not react dangerously with oil or subsurface formations and fluids. Injection of these acids have not and will not generate heat which would melt the permafrost.

Hazardous Waste

Hazardous waste is a political category of waste defined by the EPA regulations which appear in 40 CFR 261. It is a subcategory of waste handled on the North Slope. To be considered a hazardous waste, a waste must not be exempt from the regulations, and must either be a hazardous waste due to its characteristics or be a listed waste.

Materials used at Prudhoe Bay which would be classified as hazardous waste include igniteable substances which could not be used or recycled, solvents, lab wastes, some types of tank sludges and heat exchanger sludges. These materials are not acutely hazardous.

At present less than about 1/2 bbl of hazardous waste per month is produced by AAI at Prudhoe Bay. If we assume all the North Slope oil fields (Kuparuk, Endicott, Milne Point, and Prudhoe Bay) produce twice this amount of hazardous waste, a volume of 4 bbl of h.w. would be generated per month. If injection of hazardous waste was to resume, this 4 bbl would be mixed with the other 15,000 bbl/mo of non-hazardous waste presently injected. This volume of hazardous waste would only be 0.03% of the total oilfield waste injected each month. If EPA changes the definition of hazardous waste, the volume could change.

Alternative Disposal Practices

Alternative disposal techniques were examined in the "Liquid Waste Disposal Options for the North Slope of Alaska" report (Ad Hoc Task Group, 1986). Deep well injection, on site incineration and shipping to the lower 48 for disposal were examined as options. Assuming a waste generation load of 476 bbl/day, comparing an existing injection operation and cost from past waste shipments to the alternatives discussed in the report gives the following cost figures:

	Incinerator	Injection Well	Transportation/ Disposal
Capital (total)	$16,000,000	0	
Operating (annual)	$5,000,000	$1,400,000	
Cost/bbl	$29	$8	$540-$1600/bbl

These figures assume 476 bbl/day of waste and have certain limitations as discussed in the report. Alternatives to injection also pose certain environmental risks. Incineration will produce air emissions and ash. The ash must be disposed of properly. Transportation off site to a liscensed disposal site poses the risk of a spill during transit.

Conclusion

The oil industry has extensive experience and expertise in applying injection well technology. The unique circumstances of Prudhoe Bay(remote location away from populations, lack of any USDW, and dept of knowledge on subsurface characteristics) make this an ideal site for injection of hazardous waste. Waste injection at Prudhoe has been endorsed by Federal and State environmental regulatory agencies. Despite the suitability of injection technology and site, the regulatory process remains unwieldy lengthy, and unpredictable. Given the considerable effort required for permitting and long term liability questions, AAI has abandoned current efforts to obtain this permit. Despite waste minimization and recycling, some hazardous waste is unavoidably produced from industrial operations. The regulatory regime does not recognize this fact and has become so complex that proper waste disposal efforts are thwarted. Regulatory reform, ensuring efficient unambigous process of permiting is needed to assure proper work disposal.

Acknowledgement

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Municipality of Anchorage Shallow Groundwater Monitoring Well Site Selection and Suggestions for Data Analysis

Lawrence J. Acomb[1], Marc P. Little[2] and Keith E. Bandt[3]

ABSTRACT

The Municipality of Anchorage has initiated a program to monitor groundwater quality related to on-site septic disposal systems. One task in the program involved selecting 150 monitoring well locations. The selection of well locations was accomplished as part of a project that mapped the characteristics and the perceived potential for contamination in the areas containing on-site septic systems (Hillside, Sand Lake, Eagle River and Girdwood), and was designed to provide a basis for the interpretation and extension of the monitoring well test results. The map data were derived from existing sources and manipulated by models on the Municipality's Geographic Information System. The first model developed polygons of soils/geologic conditions, groundwater depth, slope, and development density data. The second model assigned a relative potential for contamination to each polygon based on the intersection of adverse characteristics.

General monitoring well locations were selected to provide coverage of significantly represented geologic/slope/groundwater/development level situations, subdivisions with reported high water tables, and large leach field systems. Monitoring well locations were refined based on interpreted groundwater flow directions, access considerations and local development density.

As they become available, the water quality data may be used to calibrate the models and be analyzed with respect to the conditions producing the water quality. The water quality data may be extended to other geographic areas and geologic/development conditions, utilizing the polygon data.

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INTRODUCTION

During the 1970's and 1980's, Anchorage, Alaska, experienced rapid population growth, leading to residential development in areas with less than ideal soil conditions. On-site septic disposal systems developed in some of these areas may provide incomplete treatment of the waste, causing groundwater contamination. The Municipality of Anchorage (MOA), Department of Health and Human Services, recognizing several existing problem areas and the potential for more severe contamination and public health concerns, has initiated a shallow groundwater monitoring well program.

To date, the monitoring well program has been conducted in a series of contracts which have resulted in the installation of 48 monitoring wells (contracted to Denali Drilling, 1985), water quality testing of this first series of wells (U.S.G.S., 1985 and 1986), the selection of approximately 150 additional well locations (R&M Consultants, Inc., 1986), installation and monitoring of about 30 wells in existing high water table areas (Hart-Crowser, 1986-87) and the installation of approximately 36 additional monitoring wells (Montgomery Engineers, 1987).

This paper describes R&M Consultants' (1986) selection of monitoring well locations and makes suggestions for analysis of the monitoring well water quality data. Areas containing on-site wastewater disposal systems addressed in this paper include the Anchorage Hillside, Sand Lake, Eagle River and Girdwood.

The selection of the monitoring well locations must utilize data concerning many factors, including the permeability of geologic materials, groundwater flow direction, water table depth, slope, on-site wastewater disposal vs. municipal sewer service, access and the cost of access to potential well locations, and the permitting process. The systematic identification of well locations and access requires an extensive and uniform data base and a consistent, logical method of evaluating the data.

To accomplish the systematic identification of well locations, R&M utilized the MOA Planning Department Geographic Information System (GIS). The GIS is composed of a uniform collection of maps containing information on geologic materials, landforms, vegetation, slope, water table depth, permeability, soil drainage, on-site wastewater systems, hydrography and land ownership. The map information in the data base provides much of the data needed for the preliminary identification of possible monitoring well sites. Additionally, because the maps in the data base have been computer automated (digitized) the map data can be efficiently and logically manipulated and evaluated (modeled) to help select the best areas and access for locating monitoring wells.

Leach Field Operation and Failure Related to the Geologic Environment

To create a GIS model that describes the potential for septic contamination of groundwater, it is necessary to understand the typical operation and failure of septic tank and leach field systems related to the geologic environment. The septic tank is a chambered tank which receives waste from the plumbing system of the structure. Waste treatment in the septic tank includes anaerobic biologic digestion, settlement removal of solids and sludge, and scum storage. The solids, sludge and scum are removed from the tank periodically by pumping. The liquid effluent of the septic tank is odoriferous and contains large quantities of anaerobic bacteria, nutrients, salts, suspended solids and in some instances, pathogens. This fluid is transmitted to an extremely porous seepage pit, or more commonly to a leach field consisting of a network of perforated pipe. In both the leach field and seepage pit, the wastewater is allowed to percolate into surrounding soil. In a properly functioning system, as the fluid leaves the pipe system, the waste is treated in the soil environment by: soil filtering, ion exchange, oxidation, soil sorption, aerobic bacterial action, and cooling. Under ideal conditions in the aerobic environment, digestion by soil bacteria and cooling destroy harmful bacteria within a few feet of leach field pipe. Ideal conditions generally include a well graded, coarse-grained soil with more than 10% silt, unsaturated conditions, a water table many feet below the system and moderate to gentle slope. However, as geologic conditions vary, the efficiency of the system in treating the waste may decrease.

Key to the treatment of leach field effluent is adequate residence time in an aerobic environment. In the properly functioning system, the aerobic residence is ensured by the relatively slow flow of the waste fluid through the unsaturated pore spaces of soil as it percolates to the groundwater table. The duration of the residence is a function of the permeability of the soil and the depth to saturated conditions. If incompletely treated wastewater reaches the groundwater table, aerobic treatment may continue but at a reduced rate, allowing the partially treated waste to be transported extended distances. Groundwater conditions limit system operation in that, if the groundwater table is shallow, waste may reach the water table before treatment is complete, contaminating the groundwater. If the water table is extremely shallow (near or above the leach field), the effluent will establish anaerobic conditions in the soil and may be forced to the ground surface, creating a health hazard.

In extremely coarse-grained soils, the leach field effluent may flow through the soils so rapidly that the partially treated waste reaches the water table before treatment is complete. Where shallow bedrock is present, wastewater may be rapidly transmitted through fractures or joints without complete treatment. Fine-grained soils have a low permeability rate which may allow the leach field effluent to saturate the surrounding soil zone.

The slope upon which a leach field is developed is important in that components of horizontal flow may allow the waste to surface downhill of the leach field, creating a septic spring. Slopes of greater than 15 to

25% are generally recognized as leading to potential problems. Similarly, road cuts and other excavations adjacent to and downslope of leach fields may intercept incompletely treated waste.

Finally, portions of the leach field waste stream (nutrients and salt ions) are treated by soil sorption and vegetative removal. If the leach field lies close to streams and/or lakes, incompletely treated waste may enter the surface water. Leach field-surface water separation distances of 100 to 200 feet are commonly required by health and environmental agencies. The potential for contamination increases as conditions within one variable deteriorate and as adverse conditions intersect.

MODELING METHODS

As a tool in selecting monitoring well locations, R&M developed three models that manipulate the Municipality GIS data base (Figure 1). The first model characterizes the depth to water, soil texture, slope, and level of development for areas of the Hillside, Eagle River, and Sand Lake without Municipal sewers. These factors, which are related to potential groundwater contamination, were then grouped according to the relative hazard to form a second model. The third model was developed to portray access considerations for potential drill sites.

1. Geologic Conditions and Development Level Model

The first model draws data from several elements of the GIS and recodes and integrates the data to form a map of unique polygons. Each polygon is identified by a four-digit code which describes, respectively, the depth to groundwater, soil texture, slope and level of existing development.

Depth to groundwater. The depth to the groundwater table is described in 3 categories, and is based primarily on SCS (1979) soils information and U.S.G.S. (Freethey, Reeder and Barnwell, 1974) mapping (and on landform and vegetation where data gaps occur):

1 moderate to deep - greater than 20 feet to the water table, generally providing adequate waste water treatment when soil conditions are favorable.

2 shallow - greater than 6 feet and less than 20 to the water table, indicating increased susceptibility to contamination when combined with less than favorable soil textures. Sensitive to water level changes related to increased recharge by high system density.

3 very shallow - less than 6 feet to the water table for at east two months each year. Noncompliance of the system and contamination of groundwater may be expected.

Soil textures. Soils and landform (terrain unit) mapping (SCS, 1979 & R.A. Kreig, 1981) was used to identify soil textures in 4 categories. Codes and descriptions are as follows:

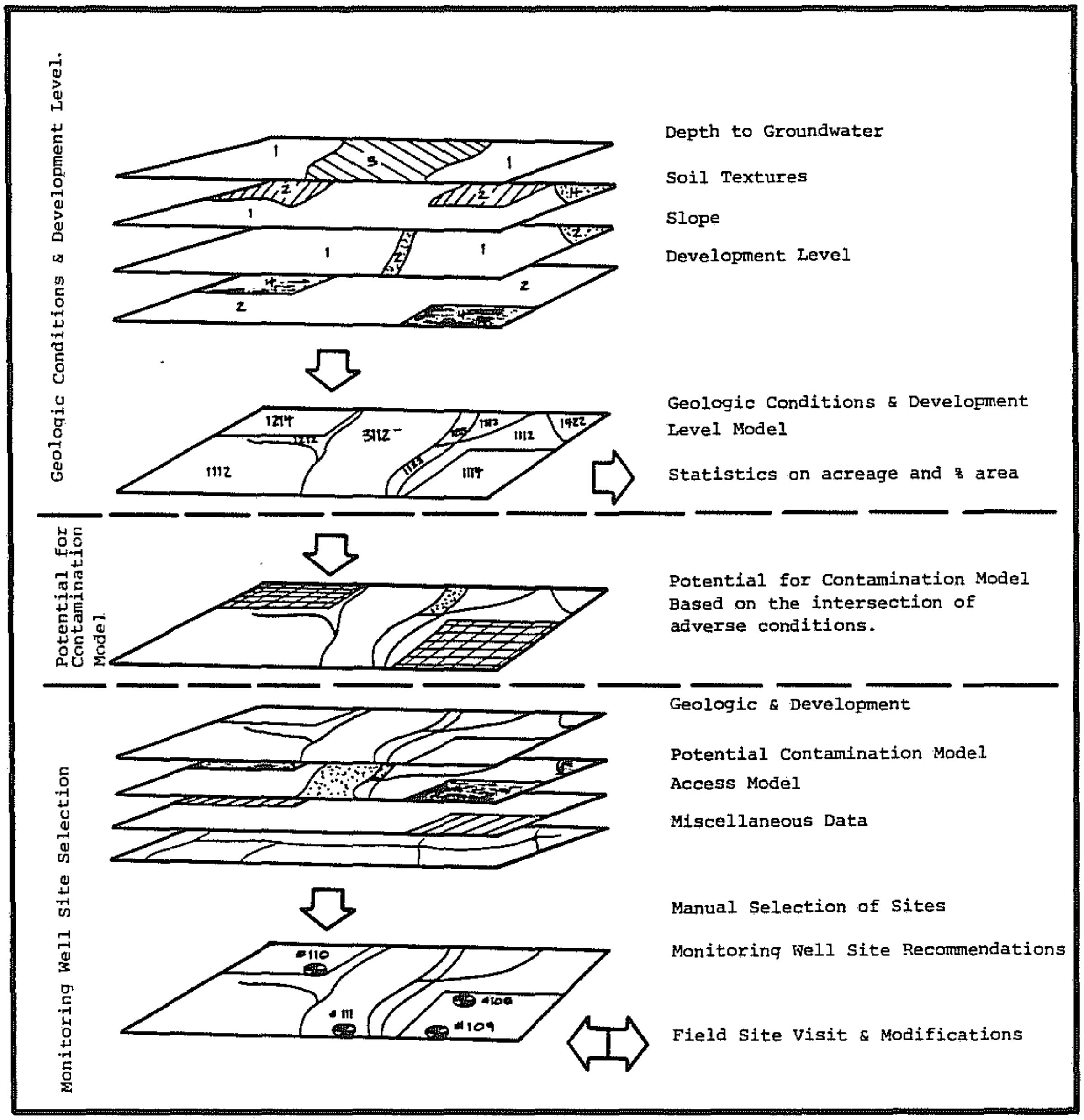

Figure 1 - Municipality of Anchorage Shallow Groundwater Monitoring Well Site Selection - Diagramatic Representation

1 medium grained - fluids percolate readily but not so fast as to allow incompletely treated wastewater to reach the water table (where the water table is at least 4 or 5 feet below the leach field; must contain greater than 10% silt).

2 coarse grained - effluent percolates so quickly that waste may not receive proper treatment with less than 20 to 40 feet of unsaturated soil (coarse sands and gravels with less than 10% silt).

3 fine grained - very limited percolation, allowing saturation and establishment of anaerobic conditions in the soils surrounding the leach field and the rise of untreated wastewater to the surface (predominately silts and clays).

4 shallow bedrock - bedrock less than about 20 feet below the surface, possibly allowing rapid transport of contaminated water through the rock fracture system.

Slope. Slope angles are described in two categories and derived from the slope data of the SCS (1979) mapping:

1 shallow slopes - less than 20% slope, where the likelihood of contaminated septic springs is minimal.

2 steep slopes - greater than 20% slope, where the probability of contaminated seepage is increased.

Development level. The development level is designed to identify the number of septic tank and leach field systems per acre in one of seven classes. The ratio is developed for each quarter-quarter section within the study area and assumes that all developed lots outside the area of public sewers have leach field systems. The greater the level of development, the greater the potential for regional water table rise, which is a documented common problem of hillside residential areas in the Lower 48, and the greater the number of people potentially affected by groundwater contamination. The system density is described with the following codes:

0 - undeveloped land, no systems
1 - developed with fewer than .25 systems per acre
2 - .25 to .5 systems per acre
3 - .5 to 1 system per acre
4 - 1 to 2 systems per acre
5 - 2 to 4 systems per acre
6 - greater than 4 systems per acre

2. Potential For Contamination Model

The geologic and development level data of the first model were modified to generate the potential contamination model. This model assigns a relative level of potential contamination to all polygon descriptions. The potential contamination ratings are based on the concepts that 1) as conditions within one variable deteriorate the potential for contamination increases and 2) the intersection of adverse conditions increases the potential for contamination. The polygon codes of developed areas were grouped based on a polygon point score. The score is the sum of the points awarded within each code category as shown below:

Assigned Point Value	Water Table Depth Code	Soil Texture Code	Slope Code	Development Level Code
.5				1
1.0	1	1	1	2
1.5				3
2.0	2	2		4
2.5				5
3.0	3	3,4	2	6

The polygon point scores are grouped into potential contamination groups as follows:

Potential Contamination Group	Polygon Point Score Range
Low	3.5 to 5.0
Moderate	5.5 to 7.0
High	7.5 to 9.5
Very High	10.0 to 12.0

The potential contamination groups were subdivided to show the potential for off-site transport of contaminants versus probable retention of waste on-site which is related to the soil texture (i.e., very coarse-grained soils and bedrock conditions tend to allow transport from the leach field area, whereas contamination in fine grained soils usually appears in the immediate vicinity of the noncomplying system). The potential for contamination in undeveloped areas was scored the same as in developed areas but was differentiated to show the lack of development and probable lack of contamination. On the model output maps, colors were used to portray the potential contamination groups with subgroups differentiated by patterns.

3. Access Consideration Model

Differences in land ownership and land use may significantly affect the permanent or long term access to the land, the cost of the monitoring program, and may have significant impacts on program schedules. Access to Municipal and some State land (road right-of-way and park land, etc.) may be obtained in about 2 months at an estimated cost of less than $1,000 per site, whereas most other access situations require similar or greater time periods and may cost twice as much. Hence, where the quality of the data would not be compromised, monitoring wells should be located on selected Municipal and State lands, including, most importantly, road rights-of-way. An access model was generated to graphically portray and summarize access situations throughout the study area. The model grouped different land ownership and land use categories based on the relative ease and cost of obtaining access.

MONITORING WELL SITE SELECTION METHODS

Monitoring well sites were selected using the GIS models depicting geologic conditions and development level and access information as tools. These data were supplemented with non-GIS topographic maps, a list of subdivisions with shallow water tables (supplied by the Municipality) and with specific schools and trailer parks as potential targets. The selection occurred in several steps. First, general site areas were selected (e.g., a subdivision or geologic situation). Then the site location within the area was refined (based on access and groundwater flow direction). Finally, the well sites were visited and modified in the field (to account for ditches, power lines, buildings and trees, etc.).

The site area selection process involved iterative manual manipulations to best fit several basic objectives, which included:

- coverage of all significantly represented (based on % area), developed, shallow water table, geologic conditions.
- coverage of all developed subdivisions reported as having a shallow water table, and/or failing leach fields;
- coverage of undeveloped geologic conditions which in other areas are significantly developed (to provide baseline water quality data); and
- coverage of specific large leach field targets such as those found at schools and trailer parks.

To assist in providing coverage of geologic conditions, statistical data were generated to show the distribution of situations in total acreage and as a percentage of each study area. Wells were allocated to each situation based, in part, on its areal significance and its development level (larger and more developed areas received more wells). Subdivisions which have a reported high water table were located on maps, and monitoring wells were located in the most restrictive portions of the subdivision (i.e. the portion of the subdivision with the highest potential score for contamination). The access model was used to locate schools with leach fields, and the aerial photos and land use maps were used to locate trailer parks with large community leach fields.

After general site areas were selected, the monitoring well locations were refined by interpretation of groundwater flow direction (based on topographic maps) and access considerations. As discussed above, most wells should be located in the road right-of-way. Because the compacted soils of the roads may act as a barrier to very shallow groundwater flow, monitoring wells should in general be located upslope of the road and downslope of the target area (i.e., the highest local concentration of leach fields) based on the interpreted groundwater flow directions. In fine-grained soils, monitoring wells should be closer to individual systems.

Field Site Visits

Well sites selected in the office were visited in the field to further refine locations. In the field, the selection principles of the office were applied to locate the wells in representative geologic situations; downgradient of the developed areas; upgradient of the road; and primarily in the road right-of-way. In addition, the field site visits allowed: 1) the locations to be modified based on the presence of ditches, steep embankments, trees, buildings, and powerlines; 2) verification of the data base and/or identification of some data base errors; 3) selection of sites using the most recent development data (i.e., that which exists in the field); and 4) the collection of site-specific data on vegetation, soil types, slope, springs, and drainage. At each well site, a field description form was completed and the site area photographed. At several sites, the well locations were modified to reflect the presence of community leach fields (however, additional undetected community systems may be present as noted on the field forms).

Finally, on each field site description sheet, the wells were given a high, moderate, and low priority for drilling. The priority rating may aid selection of final locations in a limited boring program. The priority ratings are based on the goals of the site area selection process. High priority wells are required to provide basic coverage of geologic conditions and subdivisions with reported high water tables. Moderate priority wells provide additional wells in reported high water table subdivisions, expand the geographic coverage, collect additional baseline data and further verify the data base. Low priority wells provide additional data from moderate and high priority well situations (valuable for statistical summary) and further expand the geographic and geologic coverage.

SUGGESTIONS FOR DATA ANALYSIS

The geologic and water quality data generated from the installation and testing of the monitoring wells may be used interactively with the model data to 1) calibrate the models and 2) interpret the water quality data. The soil grain size data, water table depth and slope data from the field may be used to measure the accuracy of the basic data from which the models were developed. If the basic data appear to be accurate, then the model rules may be manipulated to calibrate the models. The modifications should be made on the geologic conditions and development level model first and then on the contamination potential model. This may include, for example, changing the landform and soils grain size characterizations to correlate with the field data or modifying the point values assigned to steep slope areas to more accurately reflect the influence of slope on contamination. Finally, the point totals used to assign the high, medium, and low potential for contamination may be changed to reflect the field conditions.

Once the models are calibrated, it may be possible to geographically extend the water quality data from relatively few monitoring wells throughout the Hillside, Sand Lake, Girdwood and Eagle River areas. Additionally, the water quality data may be analyzed to reflect development densities at which contamination may begin to occur in the various geologic units, and the relative importance of the different geologic factors utilized in the models.

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LATE-WINTER CHEMICAL AND PHYSICAL CHARACTERISTICS OF THE FAIRBANKS ALLUVIAL AQUIFER

Michael R. Lilly and Scott R. Ray[1]

ABSTRACT

The purpose of this study was to observe the late-winter chemical and physical conditions of the Fairbanks alluvial aquifer. The data were collected during a four-day period from a system of US Geological Survey observation wells in the Fairbanks area. The chemical and physical parameters that were measured for the study were spatially analyzed to show trends over the study area.

Chemical analyses indicate higher concentrations for most of the major ions in the northern part of the study area. Stepwise discriminant analysis indicates that two chemical characteristics, alkalinity and potassium concentration, can be used to separate the observation wells into two distinct groups. These groups represent those wells near the possible recharge sources and those further removed from surface water recharge systems.

INTRODUCTION

The intention of the work was to determine the characteristics of the aquifer at an "instant" of time. All of the wells used in this study are part of a network of observation wells that the USGS is currently monitoring. The actual USGS well identifications have been changed to allow easier representation. The data are also plotted on each contour map at the respective well location. Each map has a reference grid on its borders for ease of locating points on the maps. Each unit of this grid is equal to one mile.

The wells only penetrated the upper six meters of the aquifer, so this study deals with the upper surface layers of the Fairbanks aquifer. Boundaries of the study area where chosen by both physiographic features and well locations. The southern boundary of the study area is the Tanana River. The northern boundary was determined by the extent of the USGS well system. Chena Ridge and neighboring well locations set the western boundary. The eastern boundary was determined by the maximum number of wells that could be analyzed by this study.

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STUDY AREA

The study area is located in the Fairbanks vicinity on the floodplains of the Chena and Tanana rivers. The topographic features of the study area are shown in Figure 1 along with the observation well locations. These floodplains are generally flat, sloping slightly toward the west with a gradient of approximately one meter per kilometer. The immediate study area is flanked to the north by the slopes of the Yukon-Tanana Uplands, and to the south by the Tanana River. The highest land surface elevation at a well site is in the northeast portion of the study area at 135.5 meters (444.5 ft). The lowest elevation of 129.0 meters (423.1 ft) is in the southeast (all elevations above mean sea level).

Chena Ridge and Birch Hill are covered on the south faces by loess deposits and underlain by the Birch Creek Schist, which is predominantly a quartz-mica schist (Pewe and Bell, 1958). The Chena and Tanana river floodplains are characterized by well-stratified layers of silt, sand, and river gravels (thicknesses up to 100 meters) with intermittent lenses of silt and sand. The upper soil layers are characterized as primarily Salchaket very fine sandy loam and Tanana silt loam (Rieger et al., 1959). The average hydraulic conductivity for the alluvial aquifer system has been reported to be 300 m/day (Nelson, 1978). This value may vary greatly on a localized scale due to changing alluvial deposits, permafrost occurrence and active layer freezing.

Intermittent permafrost in the area affects the groundwater flow on a local scale. Permafrost thicknesses vary between 0.3 meters and 80 meters, with a general increase in thickness toward the Tanana River (Pewe, 1975). Alluvial sediments with smaller grain size distributions are expected to have higher ice contents. Most river and lake areas are free of permafrost as indicated in the cross section in Figure 2.

FIELD METHODS AND SAMPLE ANALYSIS

All of the wells were sampled within a four-day period to ensure that time would not be a factor in the variables measured. Water levels in the wells were measured with a well tape prior to the removal of any sample. A small peristaltic pump was used to pump water out of the observation wells. All wells were pumped for several minutes until at least two well-casing volumes were extracted before any groundwater samples were taken. This method was tested on one well which was pumped an additional ten minutes, with no changes in the chemical concentrations observed.

Groundwater temperature, dissolved oxygen, pH, and specific conductivity were measured in the field. A YSI model 57 dissolved oxygen meter was used to measure dissolved oxygen and groundwater temperatures. The pH was measured with a portable Cole-Parmer pH

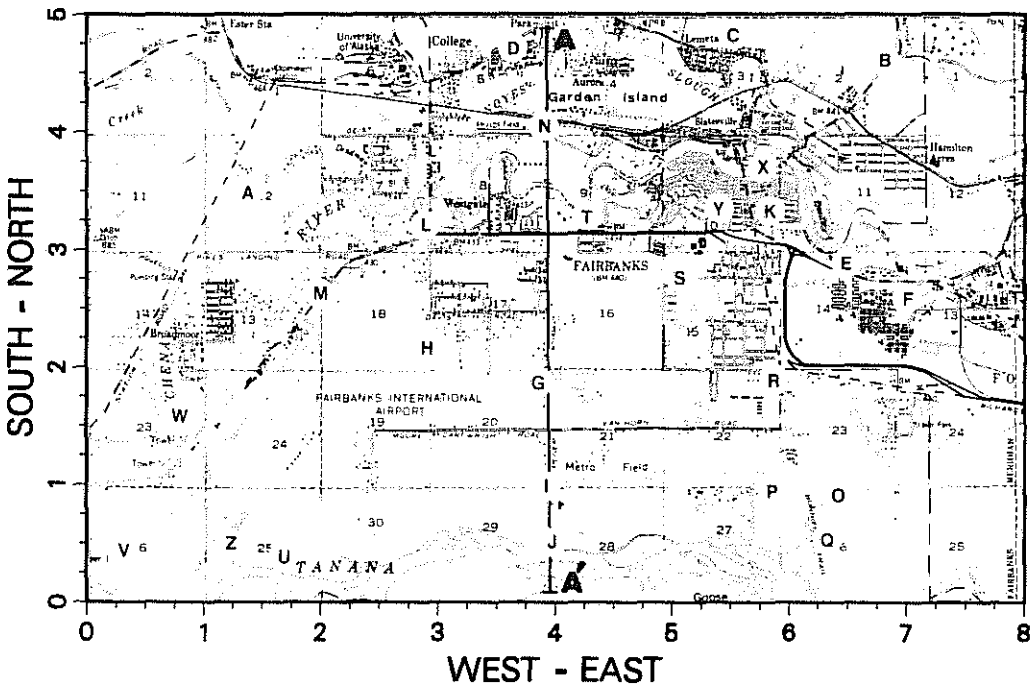

Figure 1.
Study area map for the Fairbanks alluvial aquifer.

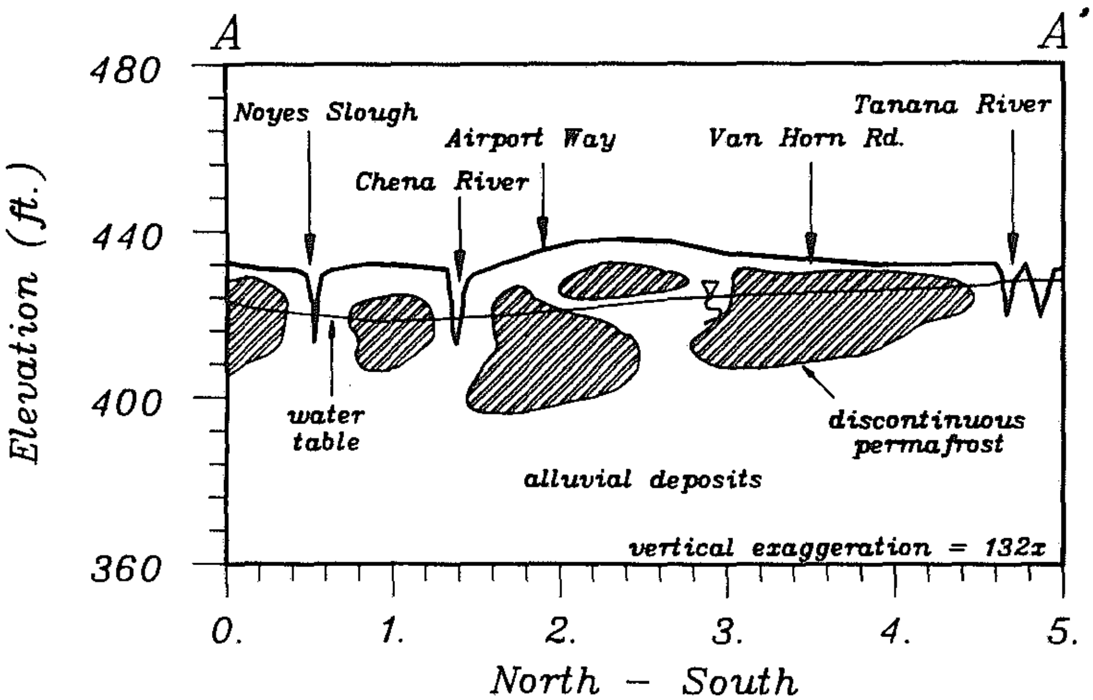

Figure 2.
Cross section A-A' through the study area.

meter, and the specific conductivity was measured with a Beckman conductivity bridge.

Samples were collected in 500 ml Nalgene bottles which were completely filled to help eliminate equilibration with atmospheric gases. Samples were returned to the laboratory in ice chests to keep the samples as near their initial conditions as possible. All chemical analyses followed standard methods as specified by APHA (1976).

The samples were analyzed for alkalinity immediately upon returning to the laboratory using a potentiometric titration and Gran plot as described by Martin (1972). The samples were then filtered through 0.45 um Millipore filters and stored in 125 ml Nalgene bottles. Three bottles were stored for each site: one each for cation, anion, and dissolved organic carbon (DOC) analysis. The samples for cation analysis were preserved with 0.5 ml concentrated HNO_3 and then refrigerated. The DOC and anion samples were frozen.

Na^+ and K^+ were analyzed using a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer. The remaining cations were analyzed with a Beckman VI Direct-Coupled Plasma Spectrometer using an argon plasma. All anions were analyzed with a Dionex 4000 Ion-Exchange Liquid Chromatography Module. The DOC was analyzed with a Sybron Photochem Organic Carbon Analyzer. All instruments, except for the DOC analyzer, were equipped with autosamplers which decreased the run time, thus reducing error caused by instrument calibration drift.

PIEZOMETRIC SURFACE ANALYSIS

Using the water-level data collected from the observation wells, a piezometric surface map was created with the Kansas Geological Survey's Surface II mapping programs (Figure 3). The polynomial regression equations created by these programs were determined by least square methods. The contour smoothing routines used piecewise Bessel interpolation within the grid cells (Sampson, 1978). The contoured surface indicates a predominant groundwater flow direction in a northwesterly direction. However, the direction of flow varies on a local scale. In the southern portion of the study area, the map indicates a direction of flow from east to west. The change in contour line orientation north of the Chena River reflects the influence of the adjacent hills.

A trend surface analysis was performed using the same Surface II routines. The trend surface provides a mathematical model which reflects the regional nature of the piezometric surface. The order of the trend surface chosen was determined by the failure of the next higher order to significantly account for additional variance (Davis, 1986). The physical geometry of the system was also used to determine the optimum surface to model the aquifer surface. This third order trend surface is shown in Figure 4. The relative x,y positions of the

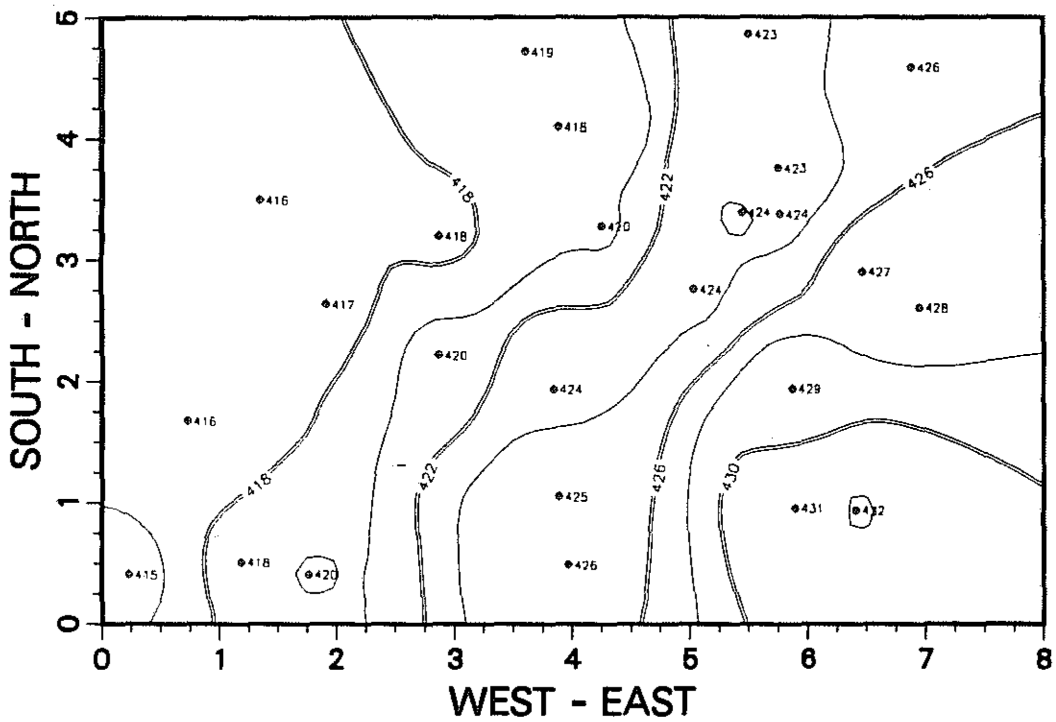

Figure 3.
Piezometric surface contour map of the study area.

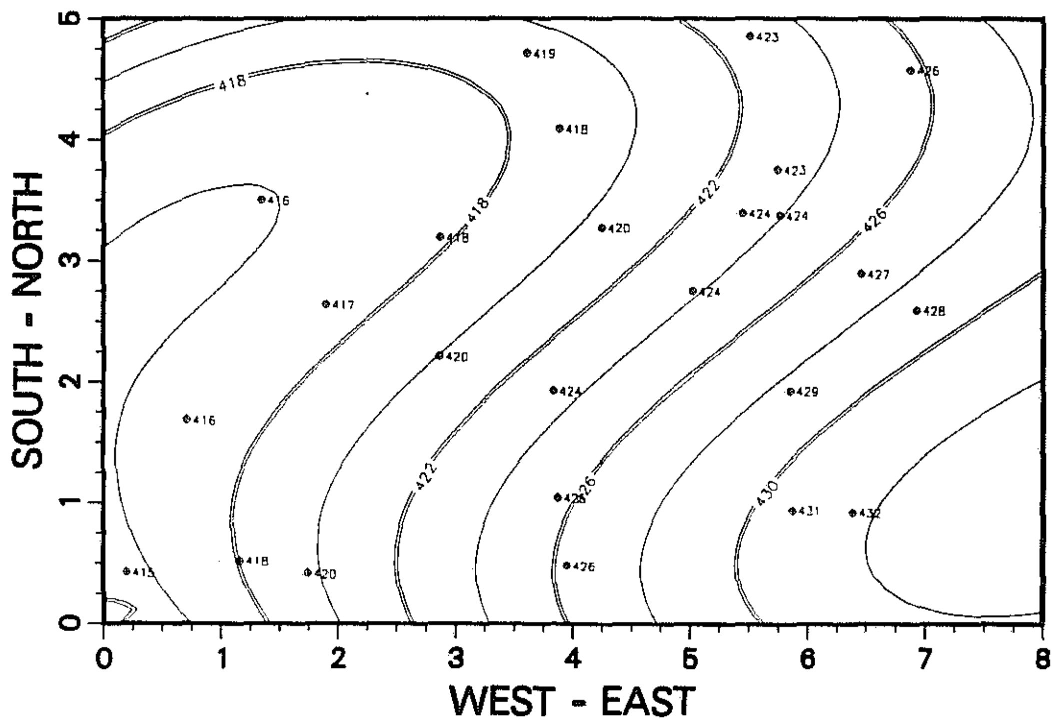

Figure 4.
Piezometric 3rd order trend surface.

observation wells and the values of the water table elevations were used to create the contour and trend surface maps. From these surfaces, the influence of the main physiographic features can be seen. These areas include the Chena Ridge area in the west and northwest portion, the Birch Hill area in the northeast portion, the influence of the Chena River through the middle of the study area, and the Tanana River at the southern boundary.

CHEMICAL ANALYSIS

The groundwater for this area has been described by Nelson (1978) as a calcium bicarbonate type. Nelson also classified the waters of the Chena and Tanana rivers as dominated by calcium bicarbonate, with total dissolved solids ranging up to 180 mg/l.

Groundwater temperatures in the wells ranged from near $0^{o}C$ up to a maximum of $3^{o}C$. The median pH value for the wells was 7.1, with one statistically unusual observation at 9.7. All well analyses showed that the aquifer was nearly depleted of dissolved oxygen, which had a mean value of 0.6 mg/l. Conductivity measurements were highest near the hills, with a reading of 1,200 umhos/cm at the base of Birch Hill. Values along the Tanana River averaged about 370 umhos/cm.

In the included plots, all of the contoured concentrations are in mg/l except for alkalinity, which is in mg/l as $CaCO_3$. Calcium values show a general decrease in concentration from a northeast to a southwest direction (Figure 5). The decreasing calcium concentration trend corresponds to increasing distance from the bedrock aquifer areas. Magnesium concentrations decrease from north to south, with highest concentrations grouped in the northcentral part of the study area (Figure 6). Sodium concentrations show no dominant trend, although well L appears anomalously high (Figure 7). This observation shows a need for further sampling in this area. Potassium concentration trends are very similar to those of sodium and are shown in Figure 8. The total iron concentrations in Figure 9 show a decreasing trend from a northeast to southwest direction, very similar to that of calcium. There are also high iron concentrations measured in the industrial area of southern Fairbanks that warrant further analysis. The overall manganese concentrations (Figure 10) in the study area are high, with all wells exceeding the recommended potable limits of 0.05 mg/l (Hem, 1970). Manganese concentrations are lowest near the river, possibly due to oxygen recharge, since the solubility of manganese decreases with increasing oxidation potential.

Chloride concentrations shown in Figure 11, decrease in a north to south direction and in areas near the influence of the Chena and Tanana rivers (Figure 11). With the exception of well R, this contour plot exhibits good separation between waters influenced by the bedrock aquifers from waters of the alluvial aquifers. Sulfate concentrations decrease from a northerly to southerly direction, with the exception

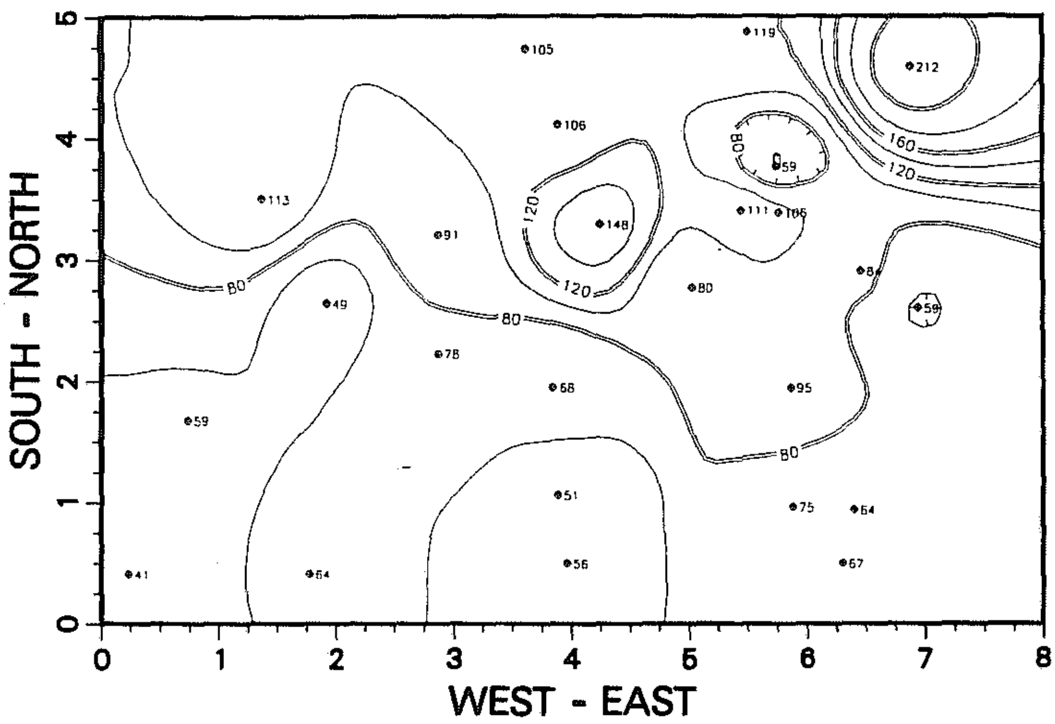

Figure 5.
Calcium concentrations contours (mg/l).

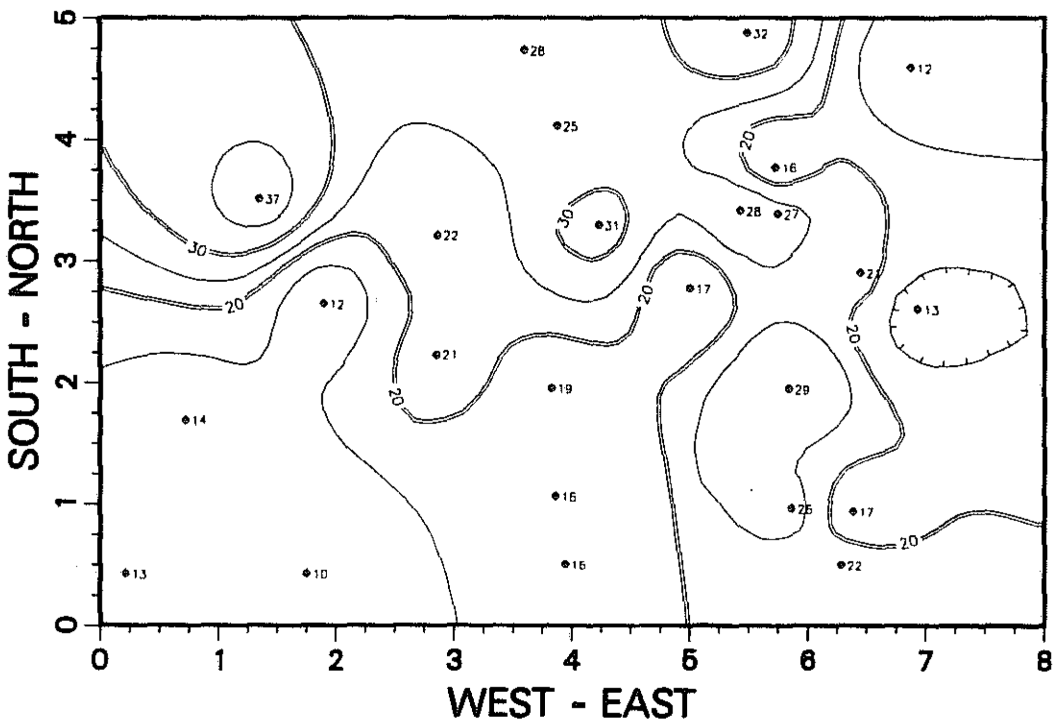

Figure 6.
Magnesium concentration contours (mg/l).

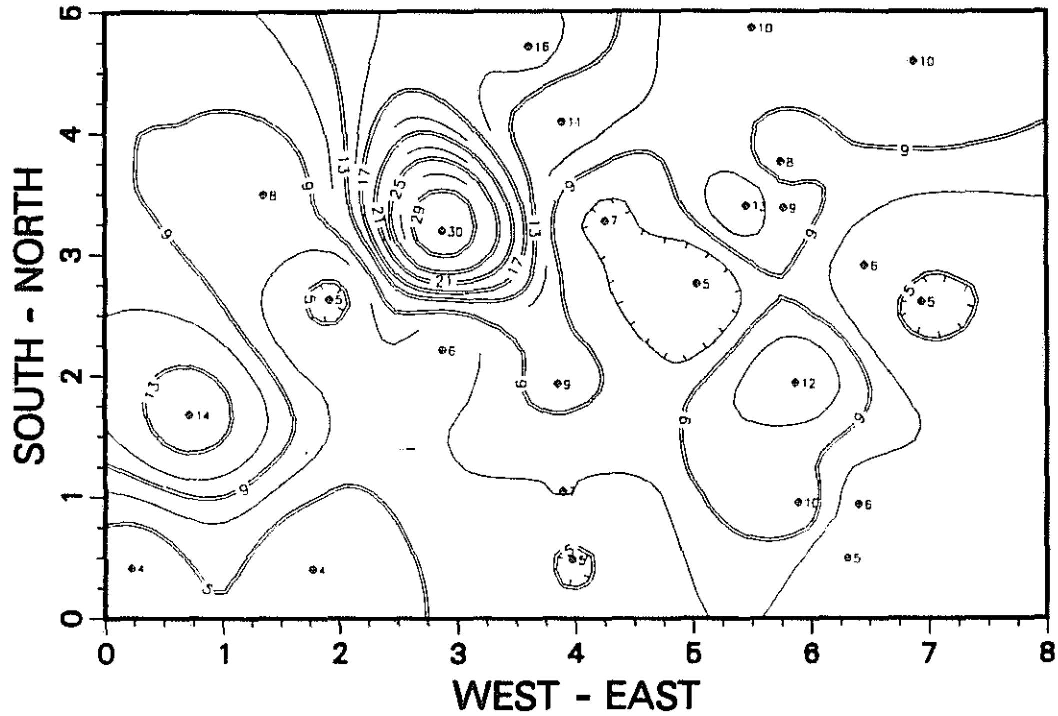

Figure 7.
Sodium concentration contours (mg/l).

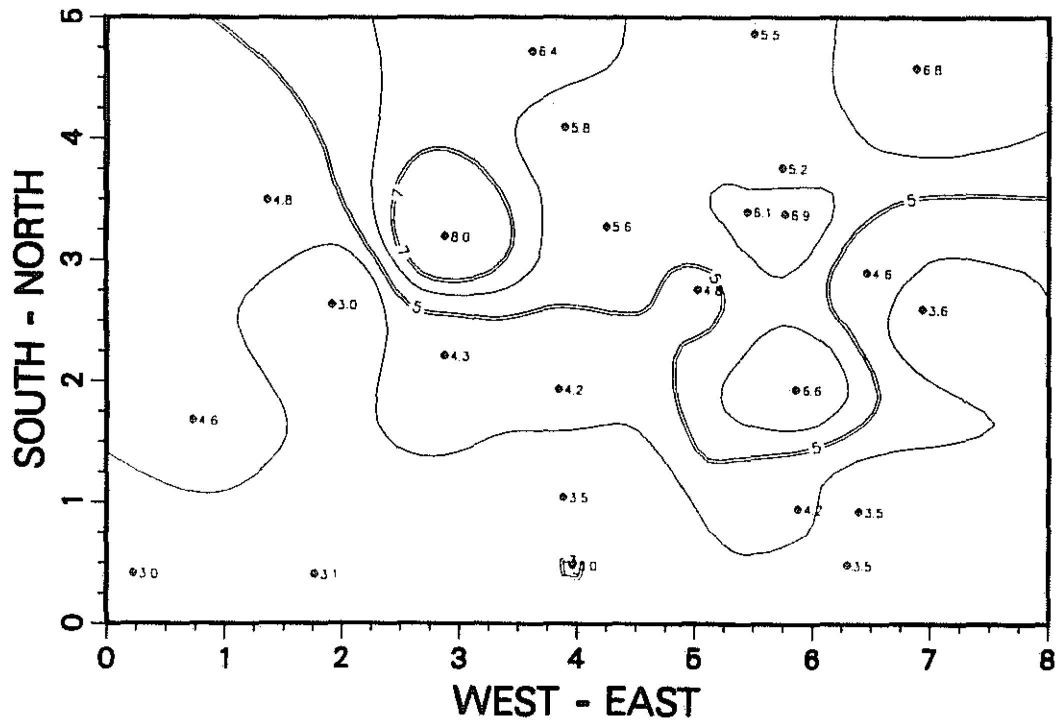

Figure 8.
Potassium concentration contours (mg/l).

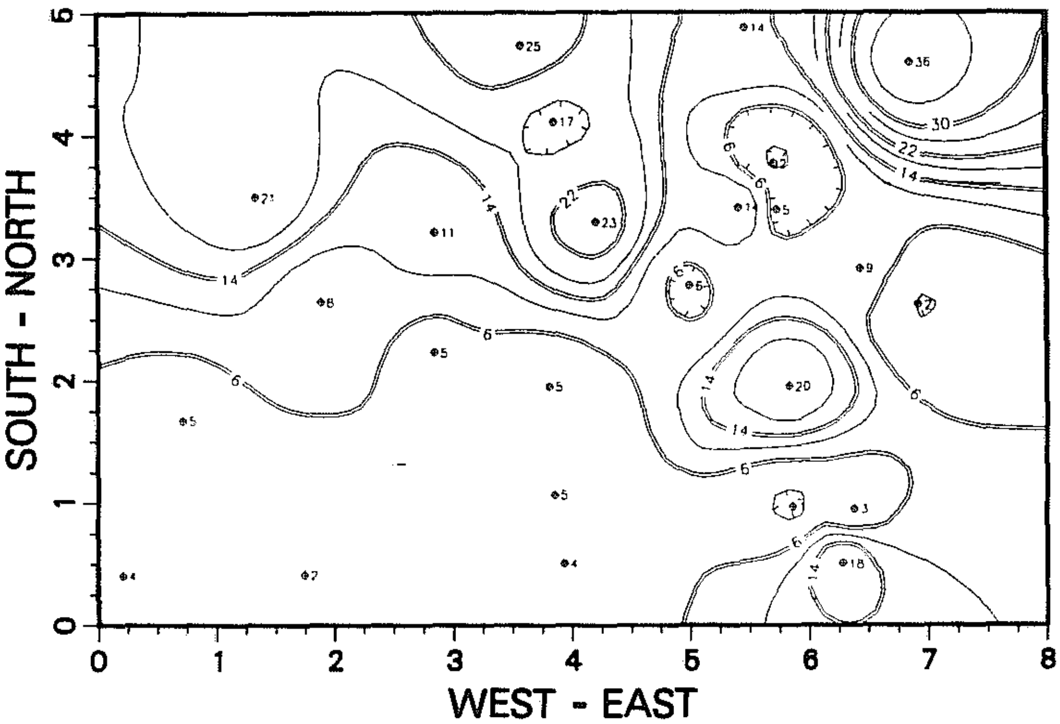

Figure 9.
Total iron concentration contours (mg/l).

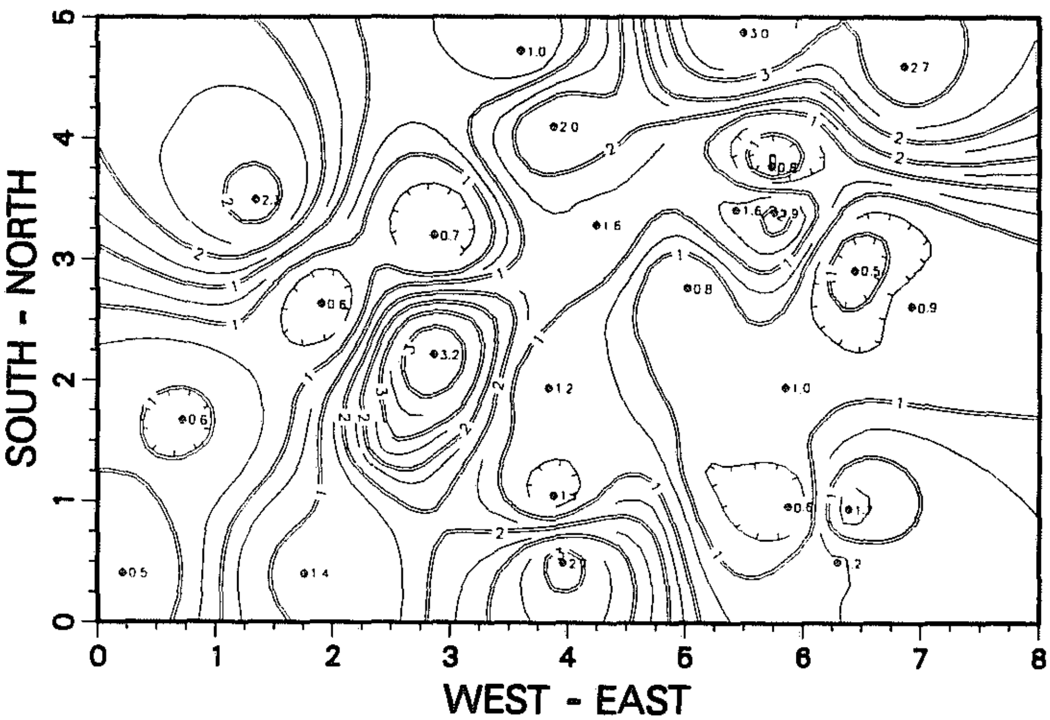

Figure 10.
Manganese concentration contours (mg/l).

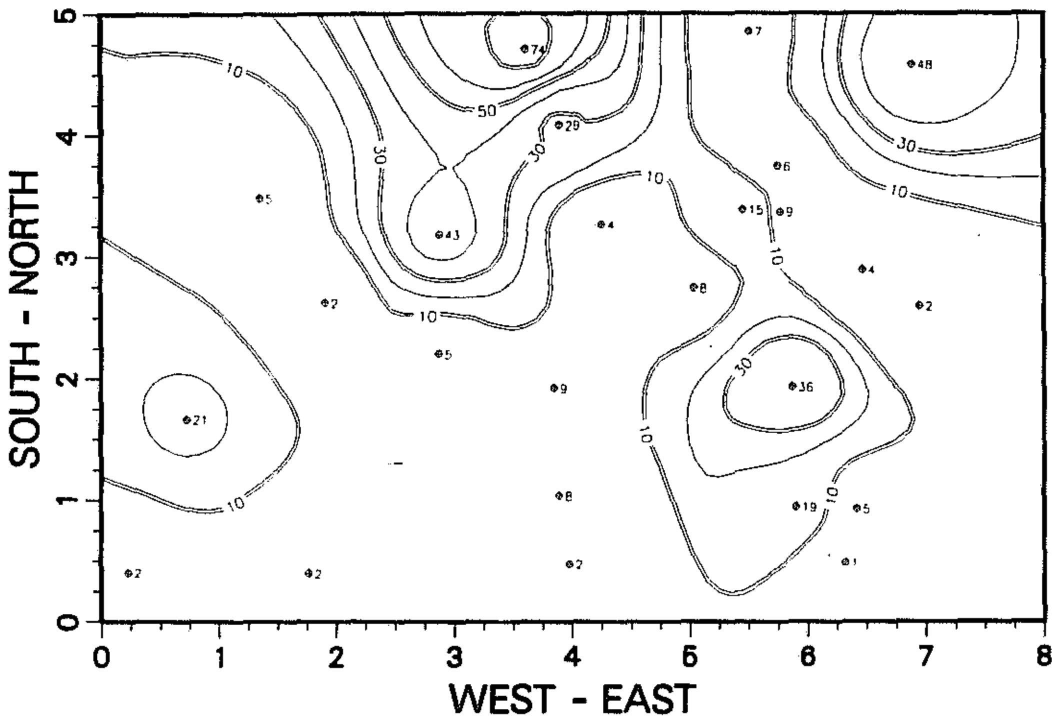

Figure 11.
Chloride concentration contours (mg/l).

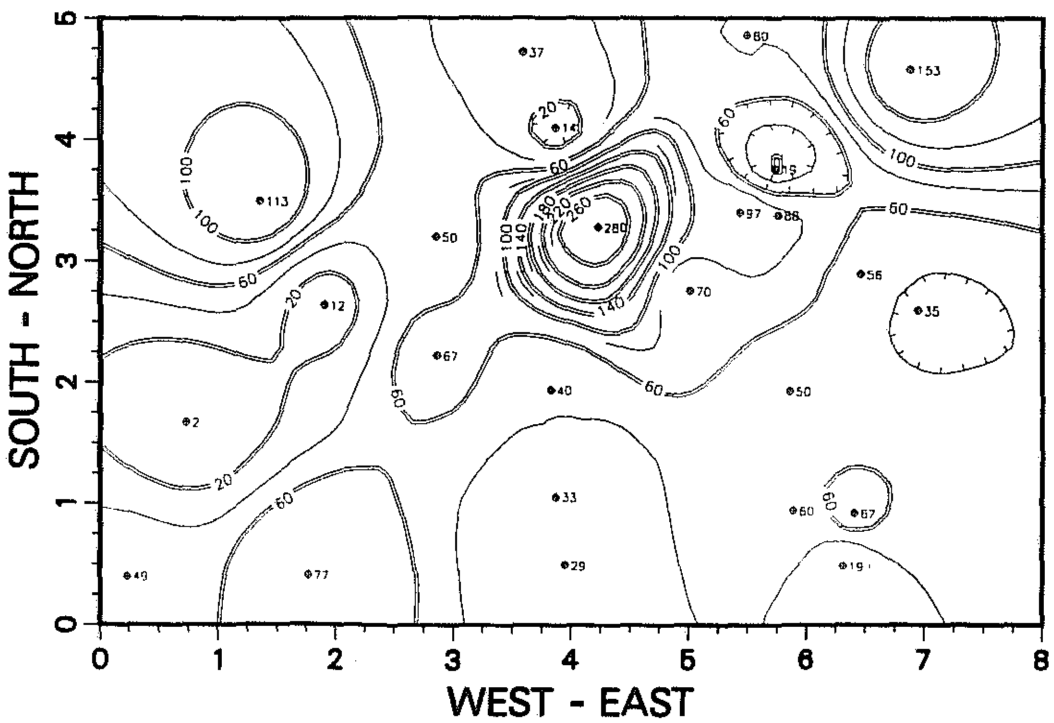

Figure 12.
Sulfate concentration contours (mg/l).

of one anomalously high value at well T (Figure 12). Alkalinity concentrations in Figure 13 show a similar trend to calcium.

Additional analyses for the following elements were performed, but no measurable amounts were found: cadmium, zinc, lead, copper, and nitrate.

GROUNDWATER GROUPINGS

The chemical results were statistically analyzed by BMDP software routines. All of the chemical data were analyzed using cluster analysis by cases. This analysis used euclidean distances to join clusters, with the values standardized to z-scores before the computation of the distances. An amalgamated distance of 2.0 was used to separate out three groups. This left six cases, or observations, to be included in a stepwise discriminant analysis, as a means for interpreting the groupings.

Discriminant analysis was used to determine if any of the chemical components could be used to distinguish grouping among the observation wells. A jackknife-validation procedure was used to reduce the bias of the group classifications. The results of this analysis indicated that potassium and alkalinity were the best components to use in grouping the samples. The canonical variables that were produced by this analysis showed a very distinct grouping of the observation well samples. This same relationship is clearly seen in Figure 14, where potassium and alkalinity are plotted against each other with the well identifications used as point symbols.

Fifteen of the observation wells have similarly low potassium and alkalinity values. The physical location of the wells indicates that river-based recharge controls the chemistry in this region. These wells are labeled as "RIVER", to indicate their possible relationship to a surface water control. One well shows up as an outlyer on Figure 14 and is labeled as "HILL". This well is located at the base of Birch Hill. Our third group falls in between the high concentration "HILL" group, and the lower concentration "RIVER" group. These wells are labeled "MIXED".

CONCLUSION

The general groundwater flow pattern in the Fairbanks alluvial aquifer study area may be modeled by a third order trend surface. Late-winter groundwater gradients in the study area are moderately flat, suggesting slower groundwater velocities. The direction of groundwater flow in the area between the Chena and Tanana rivers is better represented by a third order surface because the direction of flow is not uniform throughout the whole area.

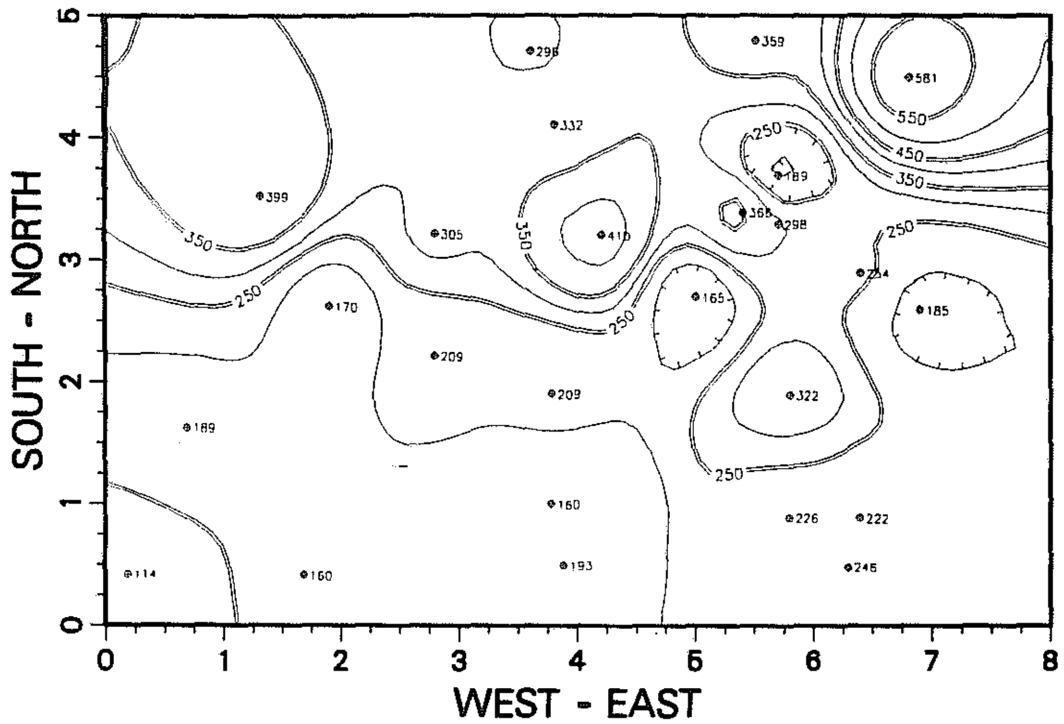

Figure 13.
Alkalinity concentration contours (mg/l as $CaCO_3$).

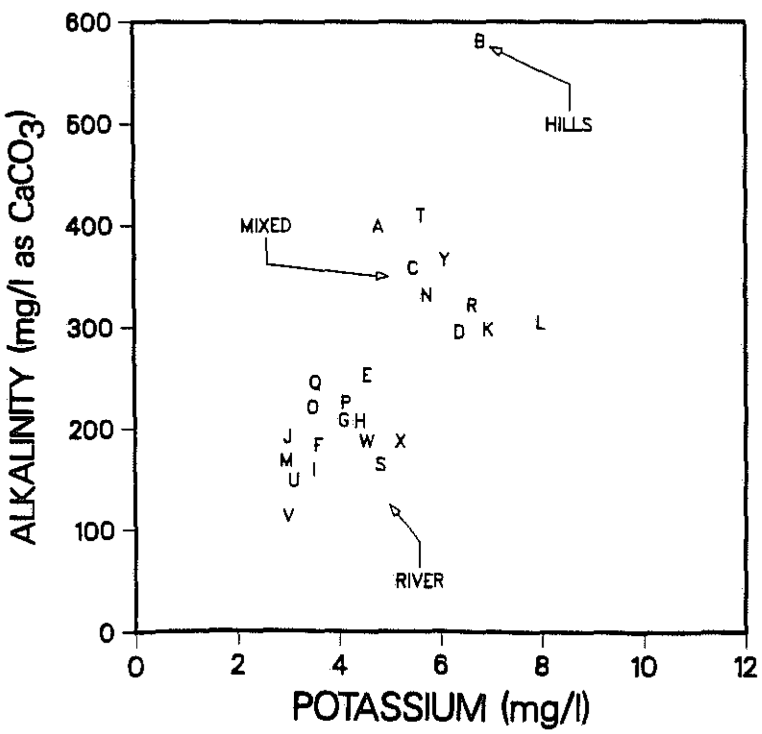

Figure 14.
Well grouping pattern, potassium vs alkalinity.

The study area encompasses two groundwater flow regimes which are separated by the Chena River, though some deep groundwater may flow under the river from the north side. This deep groundwater flow would then mix with the groundwater derived from the Tanana River. Some evidence of this may be seen in some of the chemical plots shown previously, but more work of a definitive nature is needed to resolve this particular question.

The chemistry of the groundwater may permit for the statistical separation of the groundwaters based on potassium and alkalinity alone. Groupings that are determined by this separation include water directly influenced by the Chena and Tanana rivers, one sample from the hills area and a group of samples that indicated mixed groundwaters from the hills and the rivers. The Chena River appears to contribute to the groundwater system, and it appears to affect the mixed groundwaters group by diluting the chemical concentrations of some of the wells that are just south of the Chena River.

The groundwater in the study area is depleted in oxygen, nitrate, and dissolved organic carbon. This indicates that biological activity has depleted the oxygen and carbon sources. This suggests that infiltration has stopped and these constituents are no longer being replenished.

This area needs more work to quantify the chemical characteristics of the alluvial aquifer groundwaters during the winter months and the annual cycle. More observation wells would help model of the spatial distributions of the different parameters measured in this study. Isotope studies would help define the movement and mixing of groundwater bodies within the system.

ACKNOWLEDGEMENTS

The authors thank the Water Research Center and USGS for supporting this work and all those involved with the project. We hope that this "snapshot" in time of the groundwater chemistry of the Fairbanks alluvial aquifer will help guide those who study it in the future.

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USE OF STABLE NITROGEN ISOTOPES RATIOS ($^{15}N/^{14}N$) RELATED TO NITROGEN CYCLING IN A SUBARCTIC WATERSHED

by Rebecca Johnson-McNichols[1/] and Donald M. Schell[2/]

ABSTRACT

Groundwater contamination by high concentrations of nitrate-N (NO_3- N) is a common and potentially serious problem in the upland areas surrounding Fairbanks, Alaska. No information is available, however, as to the sources or trends over time of this contaminant. This study determined natural variations of nitrogen isotope ratios ($^{15}N/^{14}N$) for a variety of inputs and process components in the nitrogen cycle of a subarctic watershed. Our goal was to use isotopic tracers to separate anthropogenic nitrate-N inputs to groundwater from nitrate arising from natural soil processes. Our findings indicate, however, that multiple processes are involved in the formation and transport of groundwater nitrate. Del ^{15}N values of well water NO_3-N varied from +4 to +11 ppt and inputs to the system from nitrogen fixation and precipitation as reflected in vegetation ranged from -2 to +4 ppt. Reduced N in septic tank effluent ranged from +5 to +7 ppt. Simplistic models which attempt to directly link sources and specific del ^{15}N values in well water nitrate are probably inadequate. Further research into the individual pathways leading to formation and loss of nitrate will help in understanding isotopic changes and possibly monitoring the contamination problem.

INTRODUCTION

History of Nitrate Contamination in the Fairbanks Area

The first mention of nitrate concentrations above 10 ppm NO_3-N in the Fairbanks area was by Cedarstrom (1963). He reported a value of 85 ppm NO_3-N measured in 1948 in water extracted from a U.S. Geological Survey (USGS) test hole (#5; located between State and Cleary streets on First Avenue). The high concentration in this water was attributed to nitrates in dynamite used to perforate the well casing. However, a concentration of 39 ppm NO_3-N was found in one shallow 6.7 meter (22ft)

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well on the corner of Third and Hall streets in 1949, which Cedarstrom believed indicated possible organic pollution. In 1954, two deeper wells of 39.4 and 50.0 meters (130 ft and 165 ft) on Steele Creek Road were tested and displayed concentrations of 53 and 65 ppm NO_3-N. Cedarstrom considered this "rather strange, as both wells are drilled in alluvium and might be considered likely to be free of organic contamination."

Since that time, wells containing high concentrations of NO_3-N were found to be common. In 1982, water from the newly-constructed Pearl Creek Elementary School yielded nitrate concentrations of 14 ppm, necessitating the installation of a second system for potable water. This finding provided impetus for this study on nitrogen cycling in the hills northwest of Fairbanks.

Nitrogen Isotope Abundances

Nitrogen occurs in two stable isotopes, ^{14}N (99.632%) and ^{15}N (0.368%). The ^{15}N content is expressed as the deviation from the ^{15}N content of air in ppt, or:

$$\text{del}\,^{15}N = \frac{^{15}N/^{14}N\ (\text{sample}) - {}^{15}N/^{14}N\ (\text{atmos.})}{^{15}N/^{14}N\ (\text{atmos.})} \times 1000$$

No detectable variations in $^{15}N/^{14}N$ ratios have been noted in air (Junk and Svec, 1958) and the biological fractionation of fixed nitrogen during metabolic processes is typically less than 1-2%, requiring sensitive isotope ratio mass spectrometry for detection. Changes in nitrogen isotope ratios in physical and biological fractionation result from both kinetic and equilibria processes during which the more tightly bound species is enriched with the "heavy" ^{15}N isotope and the product is correspondingly enriched in the "lighter" ^{14}N isotope. If the fractionations which occur in a given step are conservative in ensuing steps, the isotope abundances of the initial reactants may be used as tracers of the pathways leading to the final product.

Use of Stable Nitrogen Isotopes in Groundwater Studies

Previous studies by Kreitler (1975) and Gormly and Spalding (1979) have been able to successfully trace nitrate contaminated waters to their respective sources. A clear match was made between the well water in question and the natural or anthropogenic nitrogen sources. We sought to use the isotope abundances in natural source materials (soil organic matter, vegetation) versus anthropogenic septate nitrogen to determine the isotopic contributions from each to the nitrate in Musk Ox subdivision wells, and to develop a database of natural nitrogen abundances typical of this subarctic climate.

Study Area

The Musk Ox subdivision northwest of the Fairbanks area lies in the Yukon-Tanana Uplands physiographic province of Alaska. This region is characterized by a typical subarctic continental climate, outlined in detail by Hartman and Johnson (1984). Precipitation ranges from 10-15 inches per year of which 40% occurs as snowfall between October and April.

Geologically, the area is characterized by Precambrian schist and gneiss bedrock. Water-bearing fractures in this bedrock provide water supply to the residents. The uplands are covered with a blanket of micaceous loess, resulting from Pleistocene and early Halocene deposition (Pewe, 1955). The study area lies within a zone of discontinuous permafrost, but all of the wells studied are located on south-facing slopes which are well drained and permafrost-free.

The Musk Ox subdivision is covered by vegetation typical of early successional sequence of south-facing slopes around Fairbanks. The dominant tree species on these well-drained soils are paper birch (*Betula papyrifera*), white spruce (*Picea glauca*), and quaking aspen (*Populus tremuloides*). The green alder (*Alnus crispa*) is a common shrub in disturbed or lower-lying areas. A variety of herbaceous plants, leguminous and non-leguminous, comprise the understory.

METHODS

Field Sampling

Monthly sampling of four well sites in the Musk Ox Subdivision (FIGURE 1) was performed over a two year period. These specific wells were chosen on the basis of their high nitrate concentrations (10 to 65 ppm) determined in a preliminary study.

Water from "control" sites not impacted by human development was collected from three Goldstream springs. Fox Spring, a popular public water supply, is located 15 miles northeast of Fairbanks. The other two springs are located at 4.7 mile and approximately 6.8 mile (455 mile Alaska Railroad) Murphy Dome Road (FIGURE 1). All water samples were kept frozen in polyethylene containers until analyzed.

Samples of organic soil layers, septic effluent, precipitation, and local vegetation were also collected to provide end member signals for comparison.

Laboratory Procedures

Concentration Determinations. The nitrate and ammonia concentrations of water samples were determined on a Technicon Autoanalyzer II by an azo dye and indophenol formation, respectively.

Dissolved organic nitrogen (DON) content was measured as nitrate and ammonia following UV oxidation of the organic nitrogen (Strickland and Parsons, 1977). The sum of nitrate, nitrite, and ammonia produced equals the total N content of the sample. Subtraction of the initial ammonia and nitrate concentrations yields the DON content of the water.

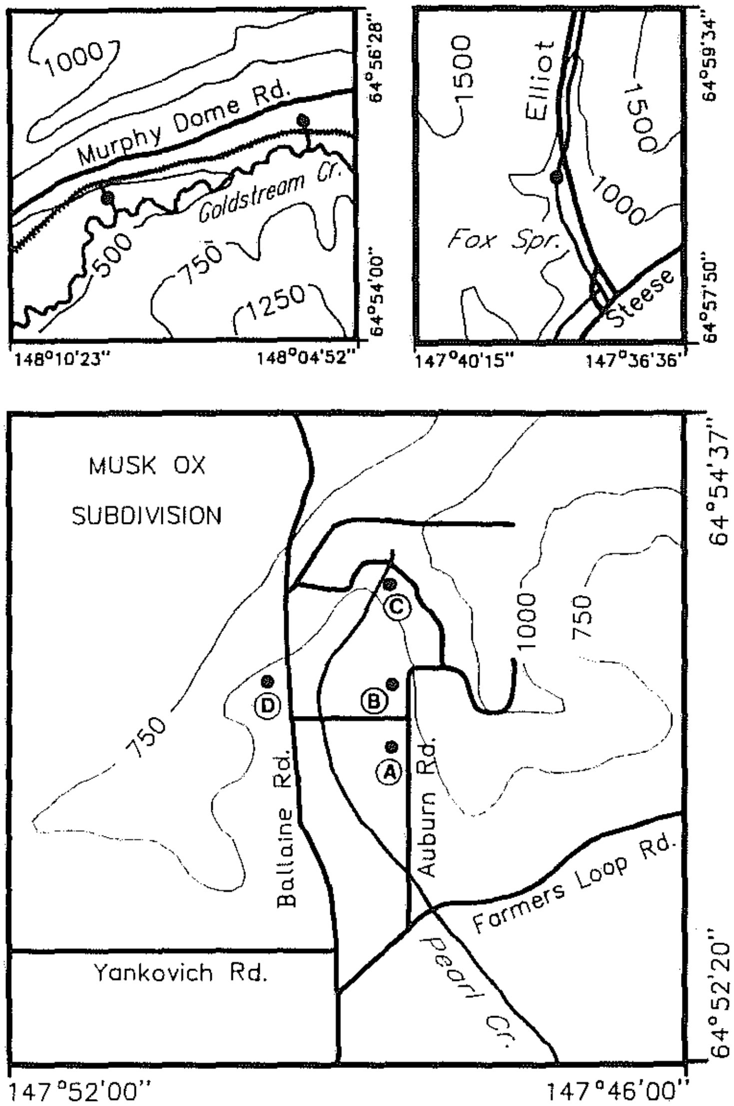

FIGURE 1. Study area and "control" sites.

Isolation of Nitrate-N. The procedures for isolating nitrate-N from natural waters have required extensive testing and modification of methods previously utilized. Samples having a negligible ammonia and organic nitrogen fraction (<5% of total N) were made alkaline (pH>9) with a few drops of 40% NaOH and evaporated down to a few mls. The concentrate was then evaporated to dryness on a precombusted glass fiber filter and dried overnight at 120^oC. All samples of well and spring water nitrate were isolated in this manner.

Isolation of Ammonium-N. An experimental ammonium- selective molecular sieve product (Ionsiv W-85, Lot #9385770002) from Union Carbide was used to recover ammonium-N from solution. Recoveries of >95% have been described for micromolar solutions (Lippschultz, 1984), but several adaptations were required for the millimolar concentrations found in septates. Following activation by heating at 200^{0} C for 2 hours in an oven, 300 milligrams of the freshly dried seive was placed on a precombusted 25 mm glass fiber filter and thoroughly washed with deionized water to remove the fines. The sample solution of filtered septate containing approximately one milligram NH_4-N was allowed to gravity filter through the seive. The glass filter and seive were placed in a vial and dried for over 12 hours at 120^{0}C.

Preparation of Inorganic N. The glass fiber filters (with or without the seive) and nitrogen sample were ground with CuO and/or metallic Cu and combusted in a double quartz tube at 870^{0}C for thirty minutes and allowed to cool to 700^{0}C over several hours. Reduced forms of nitrogen are oxidized to N_2 with CuO and reduction of nitrate to N_2 is achieved with Cu.

Preparation of Organic N. Soil or plant tissue samples containing one milligram of N (previously determined on a Perkin-Elmer 240C CHN analyzer) were ground with 1.5 grams CuO and prepared for isotope ratio analysis as described above.

Purification and Analysis of N_2 gas. The nitrogen gas produced from all samples was liberated into a vacuum manifold using a tube cracker (Des Marais and Hayes, 1976), and purified by cryogenic cleaning, then Toeppler pumped into a glass tube and sealed. The tubes were opened on the mass spectrometer (VG Isogas SIRA-9) automated sample inlet manifold, and the isotope ratio determined against a secondary standard of cylinder nitrogen gas.

RESULTS AND DISCUSSION

Groundwater Nitrate Concentrations and Isotope Ratios

The nitrate concentrations in most wells remained nearly constant for the duration of this study (TABLE 1 and FIGURE 2). The springs remained constant except during runoff months (April-May), when mixing with surface waters caused nitrate concentrations to decrease and ammonium and DON concentrations to increase. Average nitrate concentrations in well D, however, gradually increased from near 45 ppm to 58 ppm at the final sampling.

Concentration trends may be a function of the hydrologic properties of this area. Although the majority of moisture falls as rain, the most substantial recharge to the Fairbanks aquifer occurs during snowmelt at the peaks of surrounding hills where the overlying loess is thinnest and permafrost is absent. At this time evapotranspiration rates are low and the soil may still hold moisture

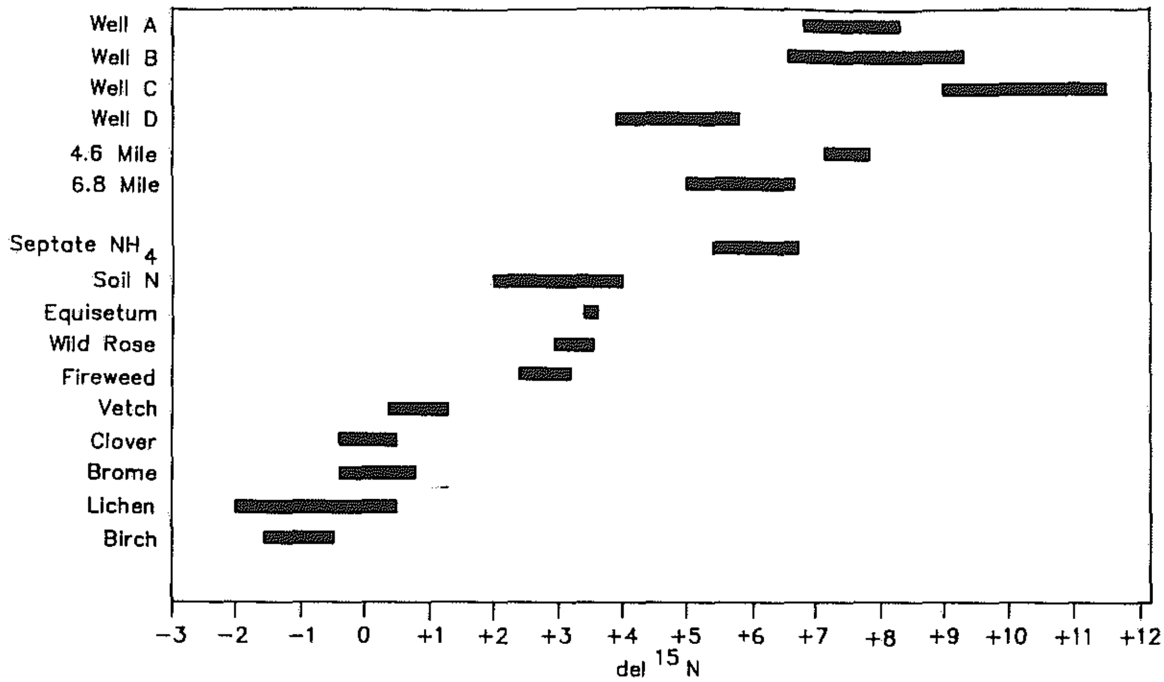

FIGURE 4. Del ^{15}N relationships among groundwaters and end members.

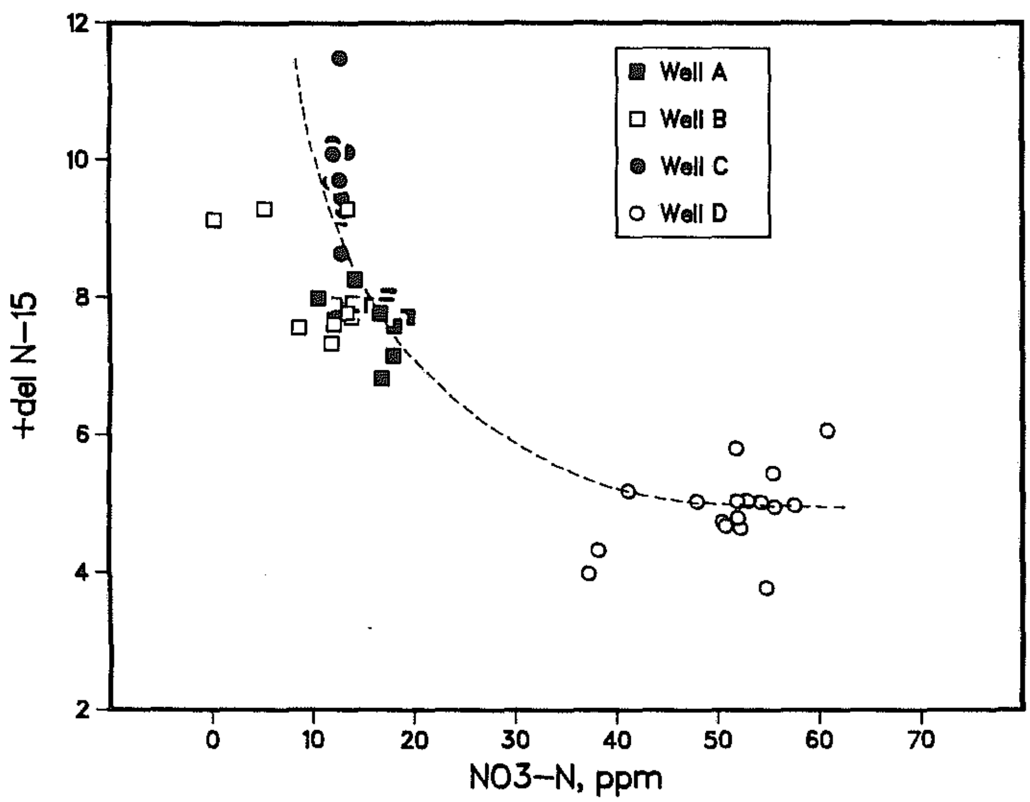

FIGURE 5. Del ^{15}N versus NO_3-N concentrations in well waters.

from rains during the previous fall (Kane and Stein, 1983). A water balance calculated according to Dunne and Leopold (1978) reveals that the recharge to the Musk Ox aquifer for the relatively dry 1985 water year was near zero inches. A continued trend in dry years and the resulting low water table recharge might be expected to lead to elevated concentrations of dissolved ions, including nitrate.

Nitrogen isotope ratios for the nitrate-N in both well and spring waters fell over a seven ppt range. Some locations were distinctly different from others (FIGURE 4). Seasonal changes in nitrogen isotope ratios, as shown in FIGURE 3, were not obvious.

TABLE 1. Organic topsoil characteristics, Musk Ox subdivision.

Sample depth	% moisture	mg N/gdw	C:N	del ^{15}N
0-2 cm	41.23	20.0	19.6	+2.05
2-5 cm	34.55	5.4	18.7	+3.28
5-8 cm	27.24	3.0	16.4	+4.07

Nitrogen Inputs

Atmospheric nitrogen. Annual average concentrations of ammonium-N and nitrate-N in rain (n=22) were 0.21 ppm and 0.14 ppm, and in snow (n=11) were 0.12 ppm and 0.15 ppm, respectively. The low concentrations in precipitation and low recharge rates to the aquifer indicate that atmospheric sources are not a significant nitrate input. Sources of groundwater nitrate must therefore arise from either biological nitrogen fixation or anthropogenic inputs.

Nitrogen fertilizers. The average del ^{15}N for three commercial N-P- K fertilizers were +1.40, +6.17, and +11.25 ppt. This surprisingly wide variation in nitrogen isotope ratios of fertilizer would ordinarily negate their usefulness in this type of study. In Musk Ox subdivision, however, agriculture is limited to a few home gardens and lawns representing a very small fraction of the total area (<0.1%). It is probable, therefore, that fertilizer inputs to groundwater nitrate can also be assumed small.

Soil organic matter. Organic nitrogen in forest soils is primarily from decaying plant litter and comprises by far the largest standing stock of fixed N in the system (TABLE 2). We have observed, as have others (Mariotti et al., 1980), that the del ^{15}N of soil organic nitrogen increases with depth indicating biological recycling and fractional loss of the lighter isotope within the soil horizon. Periodic saturation of the soils during heavy fall rains and during spring melt may create anoxic conditions with denitrification preferentially releasing the lighter isotope in N_2 to the atmospheric pool. Further biological mineralization and nitrification of the organic nitrogen will result in an ^{15}N-enriched nitrate entering the groundwater system. The end product nitrate, however, would be enriched by approximately 3 ppt during this process if the values from the Murphy Dome springs are indicative of the net processing in uncontaminated systems.

TABLE 2. Average values of nitrogen species in water samples.

Sample	NO_3-N, ppm	NH_3-N, ppm	DON, ppm	del ^{15}N
Well A	17.0	0.064	ND	+7.78
Well B	11.5	0.093	ND	+7.89
Well C	12.6	0.131	ND	+9.58
Well D	51.7	0.360	ND	+4.88
4.6 Mile Spr.	3.2	0.005	0.099	+7.55
6.8 Mile Spr.	1.6	0.013	0.068	+5.94
Fox Spr.	0.2	0.010	0.042	

Septic systems. The septic effluent samples typically contain very little nitrate (<0.015 ppm) but greater than 50 ppm ammonia and 200 ppm DON. In contrast to organic soils, septate contains nitrogen with isotopic concentrations very close to those observed in well waters (FIGURE 4). If bacterial mineralization of organic nitrogen in septic tanks was followed by recycling and isotopic discrimination in the soil column similar to soil organic matter, the anticipated ^{15}N abundances in end-product nitrate would more enriched than that observed in springs. However, if the inputs to the soil column occur below the root zone and very little biological uptake and recycling occurs, the end product nitrate may show a lesser fractionation and more nearly match the values found in well water. Thus the allocation of source from nitrogen isotope abundances of the nitrate concentrations in Musk Ox well waters presents an ambiguous problem.

A plot of nitrate concentration versus del ^{15}N of Musk Ox well water nitrate yields an inverse relationship (FIGURE 5). The wells with lower concentrations have the most enriched nitrate. Whether this reflects isotopic fractionation during denitrification or an abiotic process associated with recharge characteristics and distance of recharge is unknown.

CONCLUSIONS

This study has provided the first database on nitrogen isotope abundances in a subarctic upland ecosystem and in the associated groundwater nitrate. In progressing from recently fixed nitrogen in vegetation to soil organic nitrogen and finally to groundwater nitrate, a marked enrichment in ^{15}N occurs. This fractionation and loss of the lighter isotope provides a strong indication that nitrification and denitrification processes are closely coupled and active in subarctic soils. Further investigations into local hydrologic cycles, temporal changes in groundwater nitrate concentrations, and into the relative magnitudes of nitrogen inputs arising from anthropogenic and natural sources are needed. When coupled with better knowledge of the isotopic fractionation that occurs in the transformations of nitrogen within the soil and water, it may be possible to use isotope ratios as tracers to identify sources of nitrate pollution in groundwater.

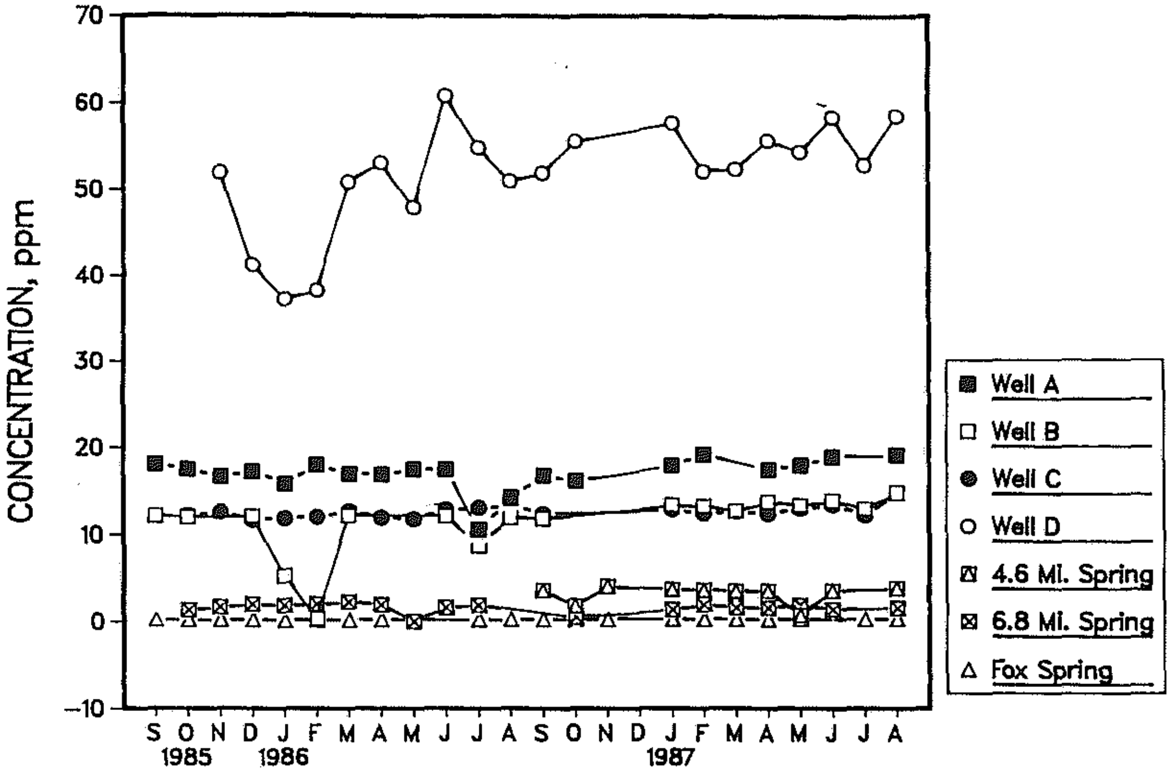

FIGURE 2. Nitrate concentration trends for well and spring waters.

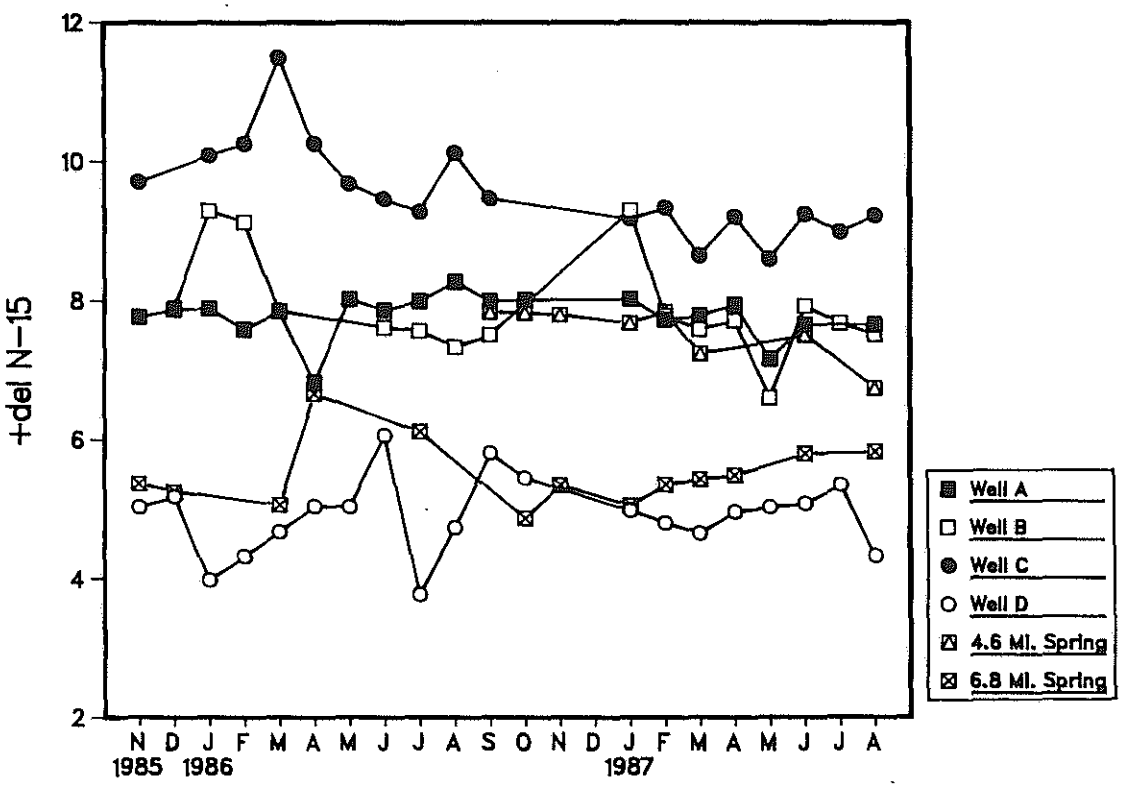

FIGURE 3. Isotope ratio trends for well and spring waters.

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SEDIMENTS AND RESOURCE DEVELOPMENT

MONITORING NONPOINT SOURCE DISCHARGE OF SEDIMENT FROM TIMBER HARVESTING ACTIVITIES IN TWO SOUTHEAST ALASKA WATERSHEDS

by Steven J. Paustian

ABSTRACT

Sediment discharge measurements taken on the mainstem of Indian River near Tenakee Springs in Southeast Alaska showed no significant change in sediment delivery following logging and road building that affected 8% of an 11 mi^2 watershed. More discrete sediment sources from road building were measured below road crossings on three first and second order tributaries to Kadashan River also located in Tenakee Inlet. Short term impacts of road building in Kadashan resulted in increased suspended sediment yield equivalent to 2% of the estimated annual sediment yields. Potential increases in total estimated sediment yield over a two year post-road construction period ranged from 10% to 66% in the three Kadashan study streams. The results of these monitoring studies have important implications for assessment of water quality management goals and objectives in the forested watersheds of coastal Alaska.

INTRODUCTION

The State of Alaska has particularly stringent Water Quality Standards for regulating the discharge of non-point source sediment into streams and rivers (ADEC, 1979). Alaska Water Quality Standards for sediment are based upon an allowable change or deviation from natural conditions. The U.S. Forest Service uses these water quality standards as a means of evaluating the effectiveness of Best Management Practices (USFS-ADEC, Memorandum of Understanding, May, 1980). Best Management Practices (BMP's) are management prescriptions that have proven to be effective in mitigating non-point source sediment inputs. BMP's are the primary control mechanism for controlling nonpoint sediment discharges into waters of the Tongass National Forest. Sediment monitoring projects have been developed over the last 10 years on the Tongass to attempt to establish natural sediment transport rates, and quantify potential sediment increases from management activities. This monitoring data also aids in assessing the relative effectiveness of BMP's in meeting water quality goals under typical forest management situations encountered in Southeast Alaska.

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Two major monitoring studies have been conducted on the Chatham Area of the Tongass National Forest. The Indian River study initiated in 1976 was designed to measure sediment relationships in large 4th order stream channels where potential impacts to primary anadromous spawning and rearing habitats are of particular concern. A second study was conducted on three small 1st order tributaries to Kadashan River to monitor more discrete sediment sources from road construction activities.

STUDY AREAS

The Indian River and Kadashan watersheds are located on opposite sides of Tenakee Inlet, northeast Chichagof Island, Alaska (Figure 1). The Indian River study area is an 11 mi^2 sub-watershed of a 21 mi^2 watershed that drains into salt water. Elevation ranges from 300 feet at the stream gage to 3,000 feet at the watershed divide. The Kadashan study area includes three 1st to 2nd order mountain slope watersheds that drain into the main stem of Kadashan River. Watersheds for these streams range from 30 to 80 acres in size.

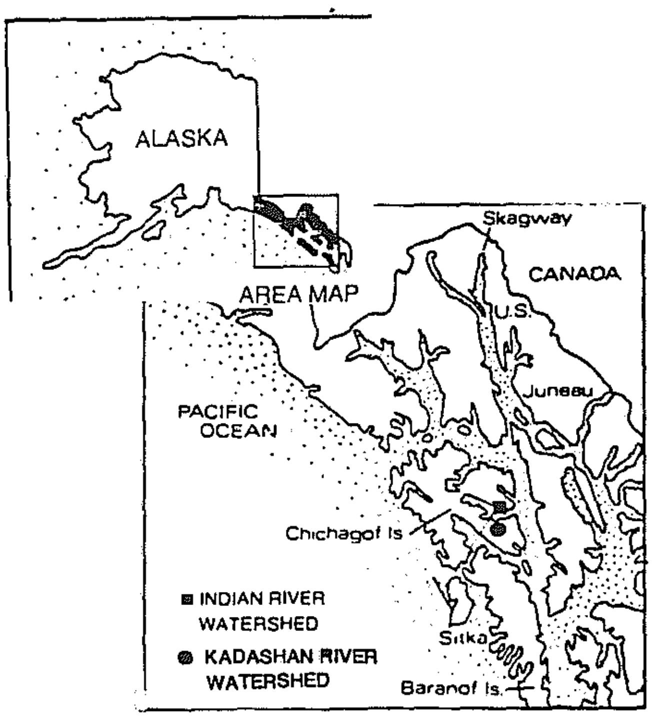


Figure 1. Map of Southeast Alaska Showing Location of Indian River and Kadashan River Study Areas.

Climate.

Climate in both study areas is typical of coastal Alaska, cool and wet. Major peak flows generally occur in the fall rainy season with secondary peaks occurring during April and May snow melt. Winter snowpack is generally intermittent below 1,000 feet in elevation. Peak flows associated with rain on snow events in January and February were observed during the Kadashan study. Approximately 40 percent of the annual 106 inches of valley precipitation occurs in September and October.

Geology.

Geology in the Indian River watershed is a mix of intrusive igneous rocks (hornblende, biotite) and metamorphic rock (marble, hornfels, schist). The Kadashan study area, located along the northeast valley wall of the Kadashan River watershed, is underlaid by intensely folded, interlayered hornfels, schist, and amphibolite (Loney, et al. 1975). Valley bottoms and footslopes in both study areas are composed of unconsolidated alluvium, colluvium, and glacial sediments.

Soils.

A wide range of soil types exist in the Indian River watershed. Poorly drained organic soils (Histosols) are found in the alpine and valley bottom muskegs. Well drained alluvial soils of Tuxekan-Tonowek series (Typic Cryofluvent-Humic Cryorthod) are widely distributed along the valley bottom. Sub-alpine brush slopes have deep, well drained, gravelly loam (Lithic Cryorthent) soils. Tolstoi soil series (thixotropic - skeletal Humic Lithic Cryorthods) are found on well drained mountain slopes. St. Nicholas soil series (thixotropic skeletal Lithic Cryaquods) are found on the somewhat poorly drained slopes.

Vegetation.

Vegetation in alpine areas are heaths, grasses, and forbs. Muskeg bogs contain sphagnum moss, sedges, and ericaceous shrubs. Forest tree species are predominantly western hemlock (Tsuga heterophylla (Raf.) Sarg.) and Sitka spruce (Picea sitchensis (Bonq.) Carr.). Alaska cedar (Chamaecyparis nootkatensis (d.Don) Spach.) and lodgepole pine (Pinus contorta (Dough, ex Loud.) are common on poorly drained sites, and mountain hemlock (Tsuga mertensiana (Bonq.) Carr.) is predominant in higher elevation timber stands.

WATERSHED TREATMENTS

Logging and Road building in Indian River.

Logging and road development began in the upper Indian River watershed during the summer of 1979 and was largely completed by fall of 1980. The baseline (natural condition) measurement period for this study is water years 1978 and 1979 (October, 1977 through September, 1979), and the post-development monitoring period is Water Years 1980 and 1981 (October, 1979 through September, 1981). Clearcut logging during this later period included; 7 cutting units from 20 acres to 50 acres in size distributed throughout the basin on flood plains, alluvial fans, and mountain sideslopes. High lead cable yarding techniques were used in all cutting units. A total of 250 acres (8% of the watershed) were harvested during the study period. Forest road building included 4 miles of haul road and two miles of cutting unit spur roads. All roads were constructed using pit-run rock overlay. Approximately two miles of the main line road was constructed on sideslopes (30% to 50% slope gradient), requiring cut and fill construction. Road running surfaces are a standard 16 ft wide on a 20 ft wide base. Exposed soil area along road cut and fill slopes were generally less than 25 ft in width.

Road building in Kadashan.

Road construction through the Kadashan study area took place in August 1984. Monitoring began in 1982 and has continued to the present time. The three Kadashan study streams are arrayed along a 1/4 mile long segment of road. The cut and fill construction road traverses 20% to 30% sideslopes. Road subgrade and surfacing is 6 inch minus crushed rock. Cutslopes have a stable 1.5 to 1 angle of repose and are mostly less than 10 ft high. Immediately after road pioneering was completed, culverts and subgrade rock were placed. Road construction through the study area was completed within a one week time frame. No timber harvest activity has taken place in the Kadashan drainages and the road has not been used to date by heavy trucks.

Best Management Practices.

Best Management Practices (BMP's) were prescribed in both study areas in order to reduce potential non-point source sediment inputs from logging and road construction activities. Logging BMP's are designed to reduce stream bank disturbance from felling and yarding timber. Log suspension is required for yarding over most ephemeral channels. Timber harvesting is not allowed on sensitive flood plain soils and highly braided channel areas. Trees are left along stream banks as needed to provide stream bank stabilization and to provide fish habitat diversity. Trees are generally not yarded across perennial streams. Road designs utilize a rolling road grade, thus minimizing the amount of road cut and fill and reducing the potential for concentrating surface water runoff on road surfaces and ditches. Slash from road clearing right of way is generally piled in windrows downslope of the road fill to act as a sediment filter. Road drainage culverts are bedded at natural channel grade with rocks placed at the culvert outlets as energy dissipators. Grass seed and fertilizer are applied to road cutslopes and ditches immediately after construction is complete. A good ground cover is established in most disturbed areas within one year. For a more detailed description of typical BMP's used in timber sales and road projects on the Tongass National Forest, refer to the The Alaska Regional Guide FEIS (USFS, 1983) and the Alaska Pulp Co. 86-90 Operating Period FEIS (USFS, 1986).

METHODOLOGY

Indian River Sampling.

Water samples for suspended sediment analyses were collected with automatic time actuated pumping samplers and DH-48, DH-59, and D-74 depth integrated samplers (Guy and Norman, 1970). The modified pumping samplers intake was located near midstream (Paustian and Beschta, 1979). Suspended sediment concentrations obtained from the pumping samplers were adjusted using a correlation with depth integrated samples. Bed load samples were also collected using hand-held and cable suspended Helly-Smith pressure differential bed load samplers. Analysis of suspended sediment samples was performed using filtration procedures recommended by the American Public Health Association (1976).

An empirical sediment rating curve approach was used to calculate suspended sediment discharges (Flaxman, 1975; Porterfield, 1972). Pre and Post-disturbance sediment rating curve regression lines were developed from log transformed suspended sediment and discharge data. A students-t test was used to test for differences in regression line coefficients (Snedecor and Cochran, 1967).

Indian River stream flow measurements were obtained from a continuous stage recorder and stilling well. Discharge measurements were obtained using a Price AA current meter by wading or from a cable car at high flows. The gauging cross-section was resurveyed periodically for stage-discharge calibration. Stream flow data reduction was performed under cooperative agreement with the U.S. Geological Survey Water Resources Division, and the results published in their annual report, Water Resource Data for Alaska.

Kadashan Sampling.

All three Kadashan sample sites, North Basin Creek (NBC), Middle Basin Creek (MBC), and South Basin Creek (SBC), were equipped with sediment settling basins and continuous stream flow recording devices. Sediment settling basins consisted of plastic lined, log-plywood dams located 100 to 200 ft downstream from road crossings. Stream flow measurement sites, located downstream from the sediment traps, consisted of flow calibrated fiberglass H-flumes with stilling wells and continuous water stage recorders. Stream flow recorders operated on a year around basis. Automatic pumping samplers collected suspended sediment samples on a nearly continuous basis during high flow periods in the spring and fall. Pumping sampler intakes were located at the sediment basin overflows in order to sample suspended sediment flushed through the settling basins. Composite samples (3 to 4 samples per 850 ml bottle) were collected at 15 min to 3 hr time intervals with the pumping samplers. Grab samples taken at sediment basin spillways were used to determine representativeness of pumping samplers.

Sediment discharge was determined by partitioning the stream flow hydrograph and interpolation of sediment concentration data for each time period (Guy, 1970). When suspended sediment concentration data was not available the sediment rating curve approach was used to estimate sediment discharge (Porterfield, 1972). Sediment settling basin deposition was determined from cross-section survey transects spaced at 2 foot intervals. Bulk density and particle size samples were taken twice; immediately before road construction in July of 1984, and again two years later. Between 6 to 8 bed material samples, randomly distributed within the settling basins, were collected using a McNeil type cylinder inserted 8 to 10 inches into the substrate. Particle size fractions were determined by dry sieving. Subsamples of the substrate samples were ashed at 650 degrees C. to determine organic matter content.

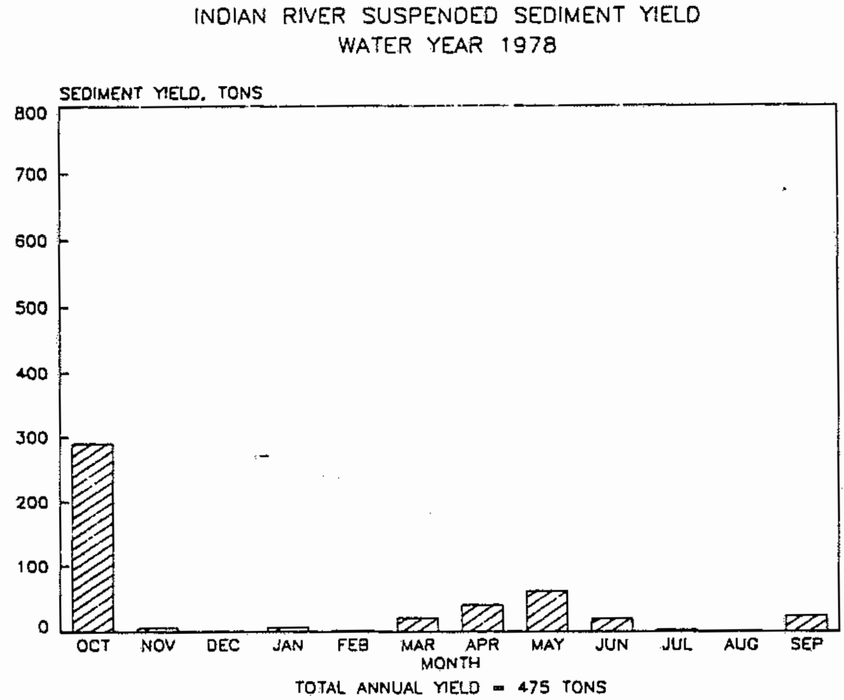
RESULTS AND DISCUSSION

Indian River.

Suspended sediment discharge (Qs) data was compiled by month for the two years preceding and two years following logging activities in the Indian River watershed. The mean monthly Qs estimates in Figure 2 and Figure 3 were derived from annual sediment discharge rating curves (Guy, 1970). The highest monthly Qs in this period of record for Indian River occurred in conjunction with unusually high runoff during October of 1979 prior to significant logging disturbance. No apparent changes in the relative magnitude or distribution of monthly Qs are otherwise indicated by the data. Total annual suspended sediment yields estimates for the monitoring period after logging - water years 1980 thru 1981- were 796 tons and 979 tons respectively (Figure 3). These values are within the range of suspended sediment yields during the pre-logging baseline period - water years 1978 and 1979 - 475 tons and 1,103 tons, respectively (Figure 2).

Sediment-discharge rating curves for the pre-logging and post-logging periods were also compared to determine if a possible change in sediment availability had occurred. Regression equations were generated from log transformation of suspended sediment concentration and discharge measurements. Each regression relationship had similar sample size (72 and 61) and similar proportions of variation (R^2 = .82 and .83). No significant difference (t = 1.30, P = .05) was found between adjusted means of the two regression lines (pre-logging log Qs = 1.33 x log Q - 2.22; post-logging log Qs = 1.46 x log Q - 2.37). This analysis validates the results displayed in Figures 2 and 3 showing no detectable change in suspended sediment delivery during the first two years of logging activities in the watershed.

Annual bed load sediments yield (Qb) estimates were not derived for Indian River. This was due to a lack of correlation between Qb samples and discharge. Campbell and Sidle (1985), and Estep and Beschta (1985), also found extremely variable bed load discharge rates in nearby



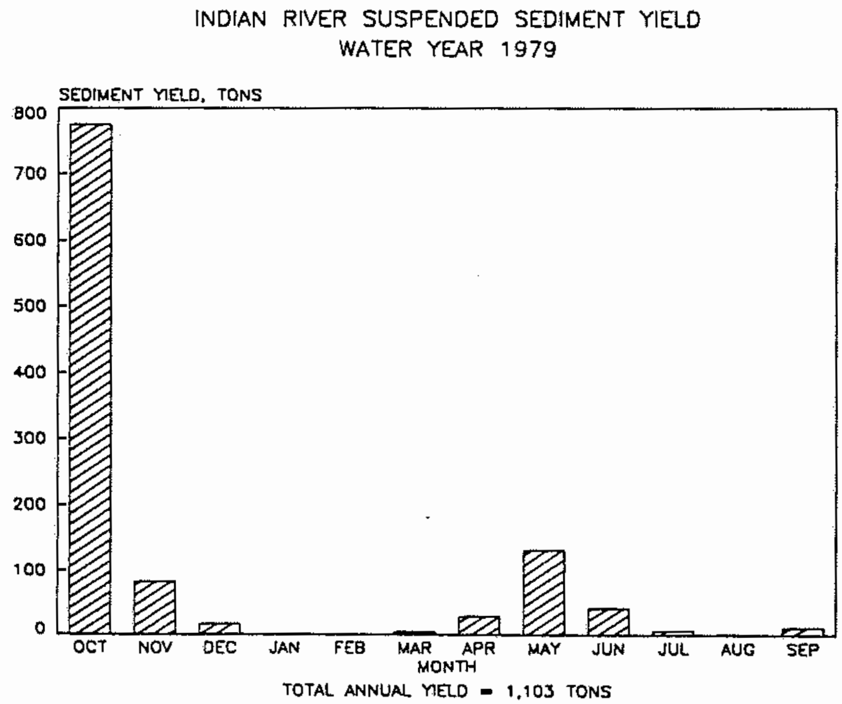


Figure 2. Indian River Suspended Sediment Yield Estimates for the Pre-Timber Harvesting Period, Water Years 1978-1979.

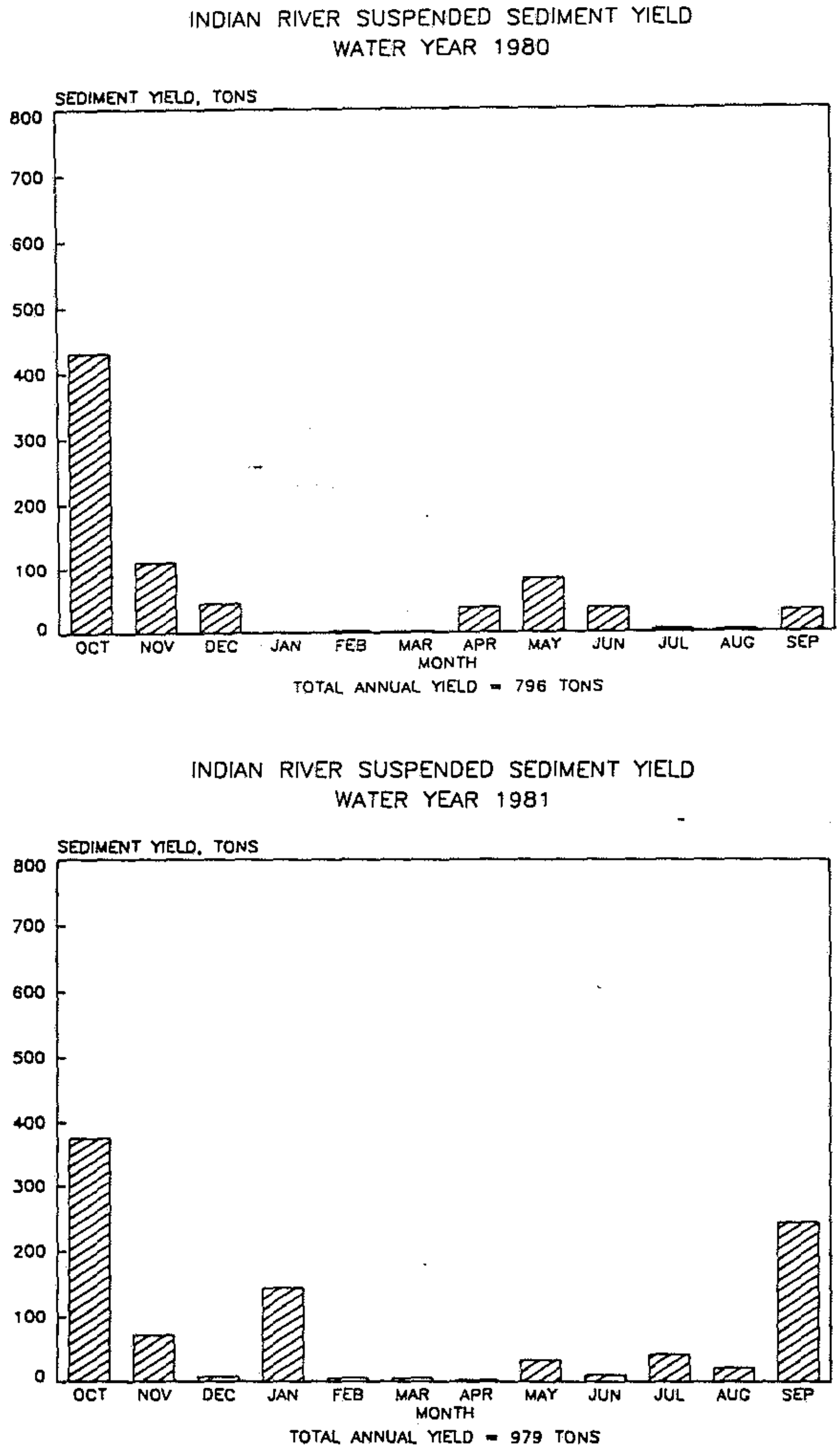


Figure 3. Indian River Suspended Sediment Yield Estimates for the Post-Timber Harvesting Period Water Years 1980-1981.

Trap Bay streams. Changes in bed load yields are difficult to detect in these types of streams over periods of several years due to large inchannel sediments storage capacity. A much more intensive sampling regimen than the one conducted on Indian River would be needed to accurately estimate yearly bed load discharge rates.

Several researchers have attributed large increases in sediment yields to road building and logging in coastal watersheds throughout the Northwest. Rice, et. al. (1979) found a one fold increase in sediment from intensive logging in South Fork Casper Creek in Northern California. Beschta (1978) observed up to a five fold increase in annual sediment yield following road construction, logging, and slash burning 100% of a small coastal Oregon watershed. Madej (1982) found an eight fold increase in sediment yield attributed to forest management affecting over 20% of a Washington watershed.

The lack of similar sediment yield changes in the Indian River study can most likely be attributed to a combination of factors including: high natural variability in sediment yields during the baseline monitoring period; successful implementation of BMP's; relatively light treatment in the watershed (only 8% of the watershed was affected by harvest units) and favorable site conditions that limited the potential of mass wasting associated with management treatments. The results from Indian River indicate that suspended sediment yields in a large fourth order watershed are relatively insensitive to small scale sediment inputs associated with logging. Although BMP implementation was largely successful, some localized areas of timber harvesting related soil disturbance, streambank disturbance, and road sediment sources were found within the study area. However, a two fold variation in natural suspended sediment discharge measured in the pre-logging calibration period, and limitations of the sampling methodology and sediment rating curve estimators (Thomas, 1985; Walling, 1977) make it unlikely that small, short term changes in sediment yield would have been detected.

The Indian River monitoring results demonstrate that using traditional sediment measurment procedures for determining cumulative sediment impacts in a large watershed may not always be the most appropriate or efficient monitoring approach. Therefore, subsequent sediment monitoring studies in the Kadashan watershed concentrated on measuring sediment production immediately below stream crossings to better evaluate the effectiveness of road construction BMP's.

<u>Kadashan Results.</u>

Sediment transport estimates for the Kadashan road construction monitoring were broken down into two time periods. The first period considered suspended sediment transport during actual road construction in August 1984. The second period considered total annual sediment yield estimates for the first two years following road construction.

Road clearing and construction took place during a summer low flow period. Therefore, limited downstream transport of sediment was expected. Little deposition of sediment was observed in the sediment settling basins during this period, however road construction did cause short-term increases in suspended sediment transport downstream of the sediment basins. The background concentrations of suspended sediment at the basin outlets during the summer generally range between 1 and 4 mg/l. During stream clearing, road excavation, and culvert placement, suspended sediment concentrations at MBC varied between 10 and 277 mg/l over a period of two days. One day after road building activity stopped, sediment levels in MBC returned to background levels of 2 mg/l. The relative magnitude of August suspended sediment yields during the study period are shown in Figure 4. Suspended sediment yield in August 1984, is two to four times higher than in other years. Although suspended sediment yields measured during road construction appear high in comparison to other years, this increase represents less than 2% of the total annual sediment yield for this stream.

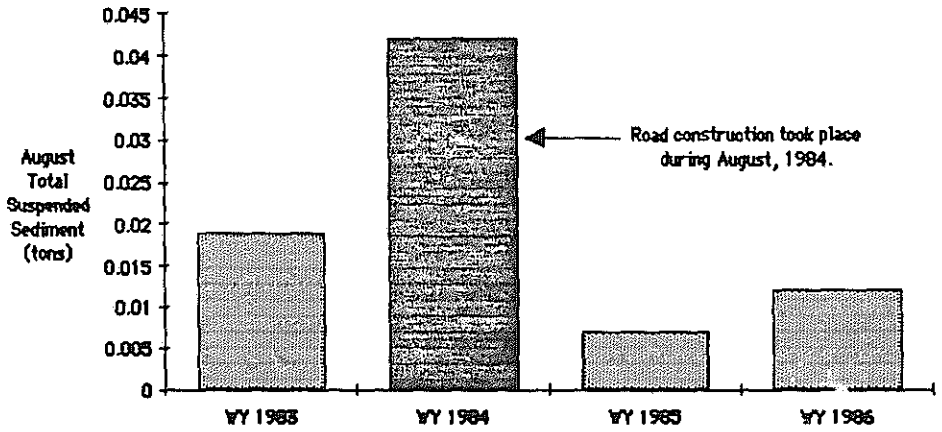


Figure 4. NBC Kadashan Suspended Sediment Yield Estimates for August Water Years 1983-1986.

Sediment deposition rates in the settling basins increased during the first two years following road construction. The settling basin, cross section transect shown in Figure 5. is representative of deposition trends in MBC which had the largest net increase in post-road sediment yield. The first full year after road construction (water year 1985) had a substantially higher deposition rate than the pre-roading period. Sediment deposition in water year 1986 was approximately 50% of the 1985 yield but was still greater than in the pre-road period (water years 1983-1984). It apparently took a period of one to two years for the pulse of suspected road related sediment to move less than 300 ft downstream into the sediment settling basins.

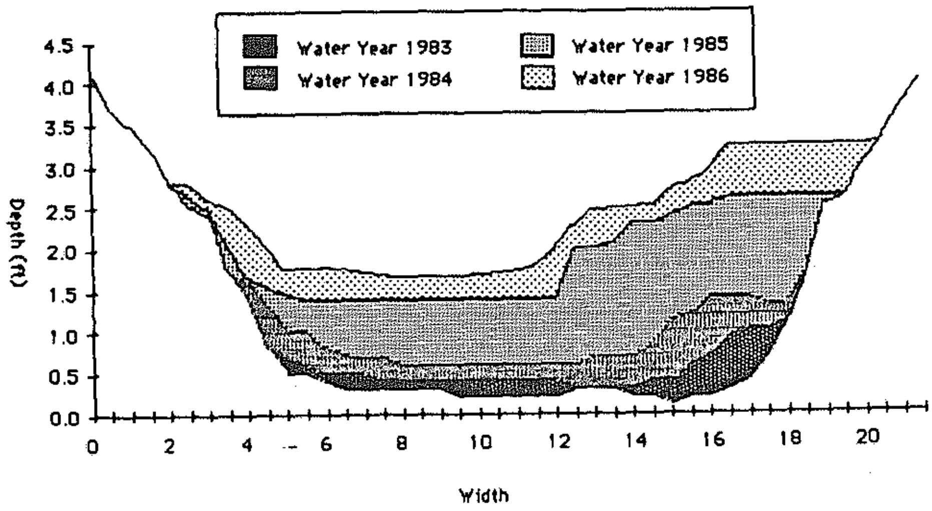


Figure 5. MBC Kadashan Sediment Settling Basin Deposition Water Years 1983-1986.

Sediment particle size samples taken from the settling basins just before road construction were very similar in makeup to samples collected two summers after construction. Organic matter composition of NBC basin deposits measured prior to road construction was 35% versus 36% after road construction. Particles sizes less than 1 mm comprised 41% by weight of pre-road samples versus 42% by weight of the post-road samples. In the 4 mm to 1 mm size ranges some difference between pre-road and post-road samples were observed; total percentages by weight were 31% and 44% respectively. Approximately 75% of the material trapped in the settling basins following road construction was composed of fine sediments less than 4 mm in diameter. Experimental additions of sediments of known volume and sizes into similar streams in Oregon resulted in analogous sediment delivery patterns (Duncan et al, 1987). In the Oregon study 90% of the introduced sediment in the .5 mm to 2 mm size fraction was trapped and stored within a 300 ft stream segment. These results indicate that small, relatively steep streams have considerable storage capacity to buffer the downstream transport of fine sediments (4 mm to .5 mm)) that are potentially most harmful to stream biota. Very fine silt and clay size sediments (>.5 mm) tend to be quickly flushed from these streams following high flows.

Estimates of total annual sediments yield are shown in Figure 6 for the pre-road period - water years 1983-84 - and the post-road period - water years 1985-86. Increases in total sediment yield were observed in all three streams during the post-road period : NBC = +.5 tons, SBC = +1.5 tons, MBC = +4 tons. This equates to a 20%, 33%, and 66% increase respectively, compared to the pre-road period. Due to the short period of record, it is impossible to determine statistically how much of this observed increase can be attributed to road construction activity and what portion could have resulted from natural variations in sediment yield. Annual runoff was very consistent throughout the study period.

The frequency and magnitude of peak flow events was also fairly consistent from year to year. Therefore, it is unlikely that stream flow was a major factor influencing variations in sediment yield.

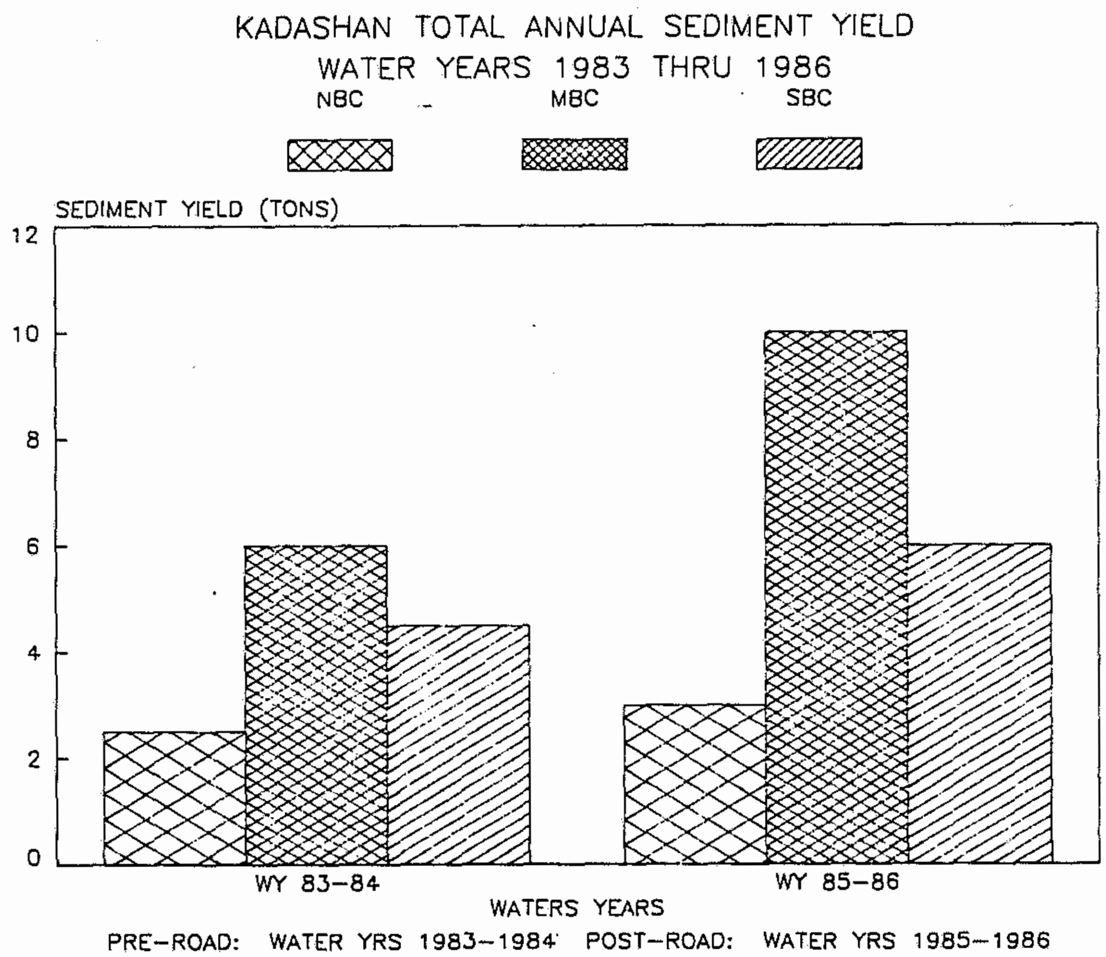


Figure 6. Total Annual Sediment Yield Estimates for Kadashan Study Sites Water Years 1983-1986.

Suspended sediment (the portion of the sediment load flushed through the settling basins) represented approximately 80% of the total sediment yield estimates for the Kadashan streams. Other studies have demonstrated that suspended sediment discharge in small mountain streams is influenced by the availability of sediment and the timing and magnitude of high flow events (Sidel and Campbell, 1985; Paustian and Beschta, 1979). Therefore, the high variability in Qs, common to small coastal mountain streams, makes it necessary to intensively sample all large flow events to accurately estimate annual suspended sediment yields. Winter floods in January and February 1985 and December 1986 created problems for estimating suspended sediment discharge from the Kadashan study streams. Pumping samplers could not be operated due to freezing temperatures and the remote sites are not routinely accessible due to weather and snow conditions. Consequently, stream flow/sediment concentration relationships were used to determine sediment yield estimates for these winter storm events. Analysis of suspended sediment concentrations from an October 84 event for MBC (following road construction) indicated proportionately higher sediment concentrations relative to discharge volume (Qv). Because insufficient high flow sediment concentration data was available to develop a new post-construction sediment rating curve, the Qs estimate for a January 85 event and a February 85 event were adjusted by a factor of +.85 using the simple proportion Qs/Qv calculated for the October 84 storm. Qs estimates for NBC and SBC were not adjusted because of lower flows and better sediment trapping efficiency. These situations illustrate the difficulties with monitoring suspended sediment at remote sites. Accurate results can only be assured with very intensive year around sampling efforts.

SUMMARY AND CONCLUSIONS

Best Management Practices (BMP's) are the primary tool used on the Tongass National Forest to mitigate the effects of logging activities on water quality. Two sediment monitoring studies conducted in the Indian River and Kadashan watersheds on Chichagof Island were designed to gather quantitative sediment yield data. This data provides a yardstick to evaluate the effectiveness of forest management BMP's in meeting water quality goals. The objectives of these monitoring studies were to establish baseline sediment yields under natural conditions and then to accurately measure changes in post-management sediment yield. Some short term degradation of water quality from increased turbidity and suspended particulates is unavoidable, particularly during road building. Under typical conditions represented by the Indian River and Kadashan study sites, BMP's were successful in preventing or minimizing sediment inputs from logging and road building to levels that are probably within the range of natural sediment yield. No increase in cumulative, sediment discharge from the Indian River watershed was detected over a two year period. Three first and second order watersheds in the Kadashan watershed had potential 20% to 66% increases in sediment yield over a two year period following road building. It is speculated that sediment inputs of this type and amount would not have been detectable in the main stream of Kadashan River due to large inchannel sediment storage that tends to attenuate sediment delivery from short term disturbance.

Results from these monitoring studies also demonstrates that precise quantification of natural and management induced sediment yield presents a difficult sampling problem. Extreme variation in temporal sediment discharge, both seasonally and within storm events, must be accounted for in sediment monitoring. Changes in sediment yields are particularly difficult to measure in large streams where potential sediment sources are dispersed throughout the watershed. Cumulative effects of non-point source discharge of sediment is difficult to detect in large watersheds such as Indian River where limited disturbances from logging and road building have occurred. Near-point source monitoring studies, such as the Kadashan studies on first and second order watershed, provide the most effective quantitative assessment of BMP's.

The two study areas discussed in this paper are representative of typical valley bottom road building and logging situations in coastal Alaska. Future monitoring is needed to evaluate current management practices under difficult site conditions, such as areas prone to mass wasting. These investigations would aid in the testing and refinement of BMP's under more rigorous conditions that cannot always be avoided in the course of forest management activities. These studies did not address potential long term affects of heavy road use and road maintenance on sediment yields. Reid and Dunne (1984) have reported sediment contributions 130 times greater on a heavily used forest road segment in the Olympic Mountains of Washington compared to an abandoned road. The issue of sediment generated by road use deserves attention and may be a focus for future monitoring at the Kadashan study sites.

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Summary of DGGS Research Related to Placer Mining, Birch Creek Drainage, 1984-86

by Stephen F. Mack and Mary A. Moorman[1]

ABSTRACT

In the Birch Creek drainage DGGS researchers, as part of the state interagency placer mining research project during the 1984, 1985, and 1986 field seasons, observed turbidity, total suspended solids, settleable solids, and discharge at approximately 20 sites, and examined water chemistry at 26 sites in 1984. With the 1985 field season we started to extensively use automated equipment to collect water samples and record water levels.

Water chemistry data indicate that pollution from placer mining is primarily tied to sediment. Turbidity and suspended sediment monitoring demonstrates that in general, sediment levels are highest at sites close to mining. On streams with no mining sediment levels remain low throughout the summer. Analysis of the settleable solids data show a pattern more closely related to stream velocity than to turbidity. Monitoring indicates turbidity concentrations at sites close to mining has decreased each year, but when turbidity is translated into index load, the difference is less apparent. The loading estimates illustrate the orders of magnitude difference between the sediment carried by mined and unmined streams and can be a mechanism for setting treatment goals for individual mining operations and streams. An intensive look at Mammoth Creek in 1986 demonstrated that reduced water use by mining operations could significantly reduce sediment loads downstream.

INTRODUCTION

The environmental impacts of placer mining on stream water quality and the economic impacts of increased enforcement of regulations on the placer mining industry are the subject of mounting public debate and controversy in interior Alaska. Each summer seems to bring new crises and new solutions for miners, regulators, and interested citizens concerned with the situation. Eventually, flaws

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in the 'perfect' solutions are revealed and the crises are resolved. Mining is not shut down, nor do streams with substantial placer mining upstream run clear. Throughout all this, regulatory agencies are revising enforcement strategies and the mining industry is coming up with new ideas for water treatment. During the controversy, public scrutiny, enforcement changes, and technological improvements, important questions have been "What is the effect of placer mining on downstream reaches?", "Is the water quality of the streams impacted by mining improving?", and this year, "What is the cumulative impact of mining on the stream basin?"

For the past four summers (1984-87) as part of a state interagency research group, the Alaska Division of Geological and Geophysical Surveys (DGGS) has been trying to document answers these and other questions. Initially, the research project focused on the Crooked Creek drainage, a tributary to Birch Creek. The Birch Creek Basin which is approximately 100 miles north of Fairbanks and road accessible by the Steese Highway has been mined since 1894 (Cobb, 1973). During the 1980's it has been the area with the most placer mining in Alaska (Bundtzen and others, 1987). The first year (1984) we measured discharge and collected samples for analysis of water chemistry at 26 sites on 16 streams, including sites above and below mining on mined streams, as well as on unmined streams. We also initiated periodic monitoring of discharge and turbidity at selected road-accessible sites. Our monitoring and data collection efforts have gradually expanded in areal scope to include sites on the Tolovana River,in the Fortymile River basin, and on Goldstream Creek during the 1987 field season. The results from the first three years (1984-86) have been reported in two separate publications (Mack and Moorman, 1986 and Mack and Moorman, 1987). This paper summarizes what we feel are important results from our work in the Birch Creek Basin.

METHODS

Water Quality

Water quality analyses were conducted in the field and in the DGGS hydrology lab located on the University of Alaska, Fairbanks campus in the Water Research Center. Major cation and some trace metal analyses were also performed with the generous help and use of equipment of the UAF MIRL.

For 1984 water chemistry analyses, field determinations at each site included settleable solids (SS), temperature, specific conductance, pH, and alkalinity (electrometric titration). Samples collected at each site were filtered untreated and filtered acidified aliquots for determining dissolved major anions, cations and trace metals; nonfiltered untreated aliquots for determining turbidity and total suspended solids (TSS); and nonfiltered acidified samples for determining total recoverable metals.

Samples for turbidity and TSS analyses were collected by automated samplers, by grab methods, or by depth integrated methods in well-mixed reaches at sampling sites. When automated samplers were employed, the intake hose was installed at mid depth pointing upstream. Automated samplers used in 1986 in the Birch Creek Basin were programmed to composite into one bottle four samples taken six hours apart each day.

Settleable solids were measured in the field using Imhoff cones with a limit of detection of 0.1 ml/L following standard procedures (APHA 1985).

Discharge

The general gage locations were chosen on the basis of easy road access, that is, closeness to the Steese Highway, Circle Hot Springs Road, or other road. Mixing was a consideration for sites that were also used for turbidity monitoring. Staff gage water surface levels were recorded whenever agency personnel were in the vicinity. Water levels on staff gages at mining operations were recorded a maximum of twice daily by the local miners.

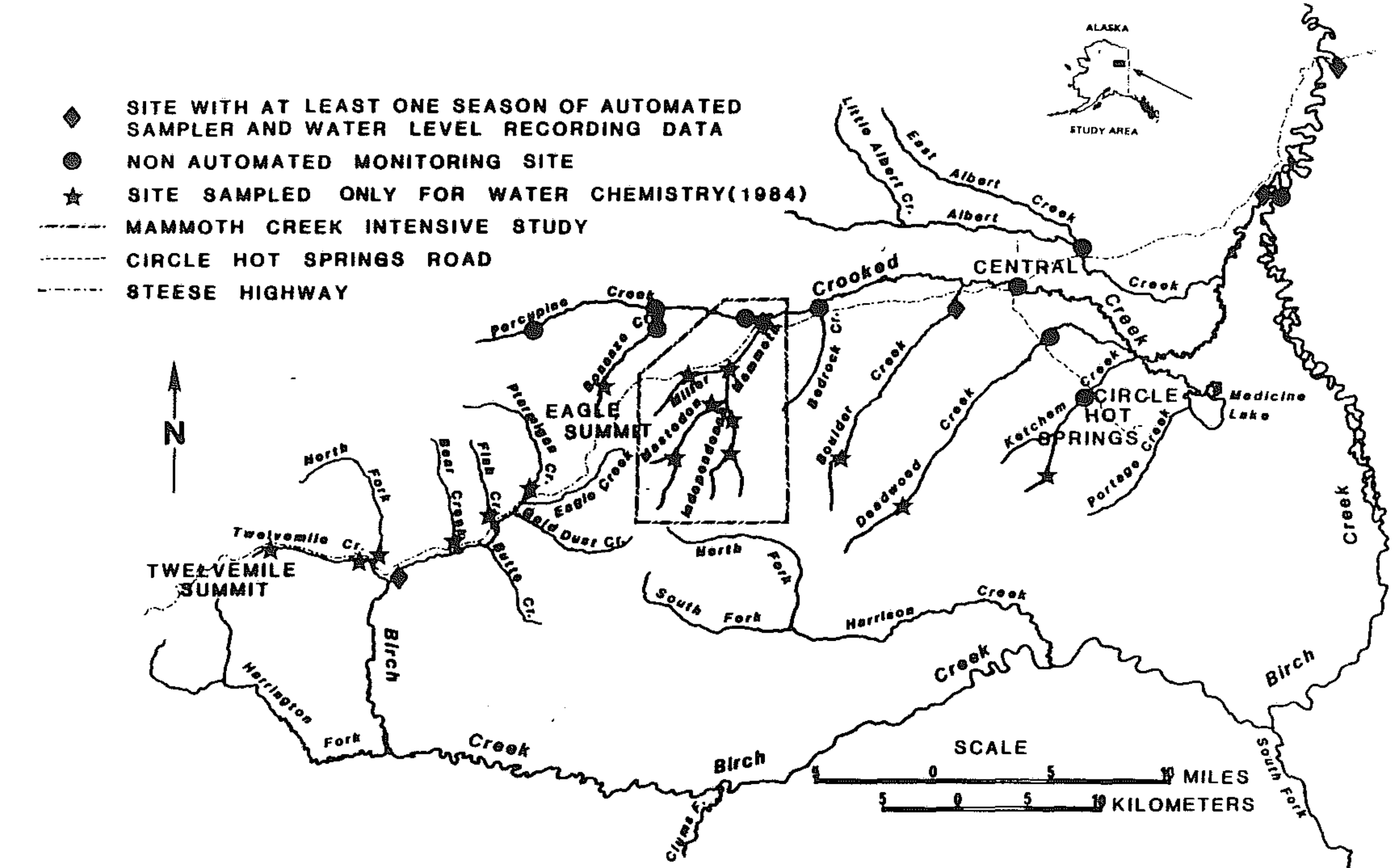
At 'automated' locations noted on Figure 1 water surface levels were recorded with Omnidata DP320 Stream Stage Recorders. The DP320 is a small, battery operated device with a pressure transducer located beneath the water surface which measures and records water levels between 0 to ten feet (to the nearest hundredth of a foot). In general, rating curves (used to estimate discharge from the observed or recorded water levels) were developed at each site using at least four discharge measurements taken throughout each field season at different water levels.

Sediment Load and Turbidity Index Load

Sediment load is calculated by multiplying discharge (in cfs) by TSS (in mg/L) and a constant, 0.0027, to put the units into tons per day. Turbidity behaves much like TSS but cannot be used to accurately estimate TSS. However, turbidity data is more plentiful than TSS data historically. Therefore, to compare water quality impacts

Figure 1. **LOCATION OF SITES FOR PLACER MINING STUDIES 1984 - 1986**

BIRCH CREEK DRAINAGE



over a longer time period we have developed a load indicator we call the turbidity index load (TIL). TIL is obtained in the same manner as sediment load - multiplying discharge in cfs by turbidity in NTU. The product is divided by 1000 to bring the results into the same order of magnitude as sediment load (in tons per day). The units for TIL are KNTU-cfs where 'K' represents 1000.

Mammoth Creek Intensive Study

The Mammoth Creek area was chosen to study various mining activity impacts to a relatively short stream reach with a number of mining operations. Sampling sites were chosen above and below all mine sites and at all important confluences. Travel times between sampling points were estimated from distances measured on maps and average measured stream velocities. A sampling schedule, based on these travel times, was established to attempt to monitor a slug of water as it passed through the system. At each site four samples were collected each day, one every four hours. At three sites automated samplers collected backup samples and collected samples through the night.

RESULTS AND DISCUSSION

Data from the 1984-86 field seasons are presented in full in the two annual reports mentioned above (Mack and Moorman, 1986; Mack and Moorman, 1987). Below are the some of the major points discussed in those reports.

Water Chemistry

Water chemistry data from 1984 indicate that pollution from placer mining in the Birch Creek drainage is primarily tied to sediment. Treatment that lowers sediment levels will also lower toxic metals concentration levels. The Alaska Department of Environmental Conservation (DEC) lists maximum acceptable concentrations of As (0.05), Ba (1.0), Cd (0.010), F (2.4), Pb (0.05), and Hg (0.002), in mg/l (in parentheses) for public drinking water systems in Alaska (DEC, 1982). None of these heavy metals were found dissolved in water of the Birch Creek drainage in excess of these limits. However, the limits for As, Ba, and Pb, were exceeded in the total recoverable analyses of waters with elevated TSS values, indicating that these contaminants remain principally sediment bound. The DEC acceptable levels for As and Pb are exceeded in total recoverable (TR) analyses of samples with TSS values of at least 430 mg/l and Ba in samples with TSS values of 4500 mg/l or greater (Mack and Moorman, 1986).

Turbidity Monitoring

Figure 2 shows average monthly turbidity values at 5 sites in the Birch Creek Basin. Birch Creek above Twelvemile Creek (UBC) and Mammoth Creek (Mam) are below active mining, Birch Creek at the Steese Highway Bridge (BC) and Crooked Creek above Birch Creek (Crk) are considerably downstream from mining, and Boulder Creek (Bdr) is unmined. These sites are representative of the sites we monitored in the Birch Creek Basin. In general, during normal flows sediment levels are highest at sites below active mining. At sites with no current mining upstream, sediment levels are consistently low. At sites far downstream from mining sediment concentrations are lowered by dilution and sediment deposition. Average turbidity concentrations at sites close to mining appear to have decreased each year in 1985 and 1986. Seasonally, no strong trend is apparent, although on mined streams considerable variation can exist between months.

Settleable Solids

We don't feel settleable solids is a good measure of the placer mining impacts on water quality in ambient stream situations. At sites we monitored, settleable solids levels appear to relate as well to flows as to sediment levels as measured by turbidity or TSS. Figure 3 shows the relationship of grouped settleable solids data to the median turbidity and velocity of each group. As SS increases, median velocity increases steadily with the exception of the 0.5-<1.0 ml/L range. The pattern between turbidity and settleable solids is less clear, especially when the nondetectable group (nd in Figure 3) is ignored. Settleable solids (as measured in an Imhoff cone) are the larger particles that will settle out in one hour. With the higher stream velocities associated with high flow events more of those sized particles are suspended in the water column.

A bigger problem with settleable solids is the relatively high lower detection limit. In Figure 3 we noted the frequency of each settleable solids group. Fifty-nine percent of the observations used for this figure were below the smallest increment (0.1 ml/L) on the Imhoff cone. We reported values to that lower limit and differentiated between trace and nondetectable amounts in the Imhoff cone. DEC (ADEC, 1986) recommends a lower reporting limit of 0.2 ml/L and that all values below 0.2 be reported as "less than 0.2 ml/L". If we had followed that procedure with the observations used for Figure 3, eighty percent of our data would fall in the "less than

Figure 2. AVERAGE MONTHLY TURBIDITY INTO BIRCH CREEK BASIN

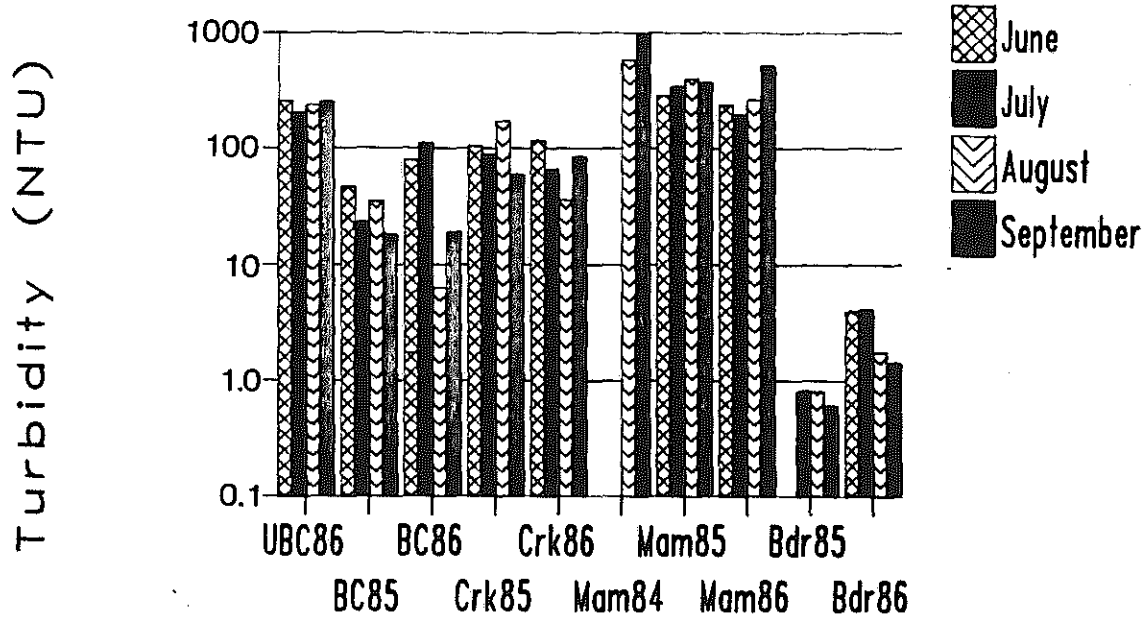
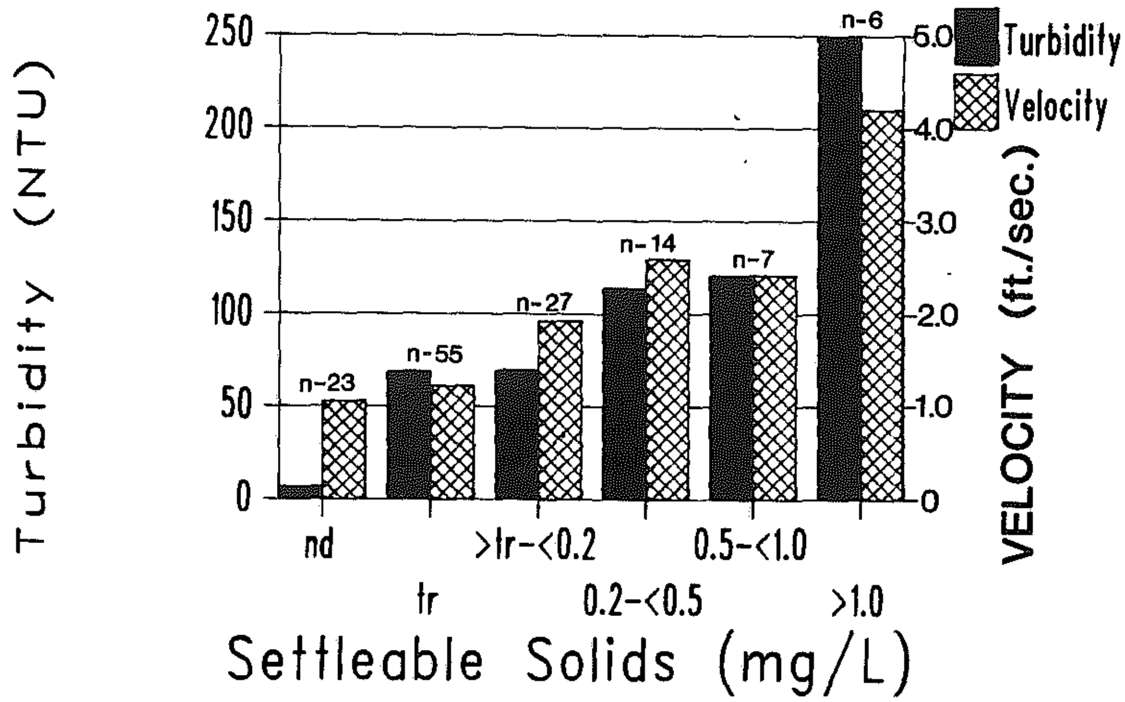


Figure 3. RELATIONSHIP OF MEDIAN TURBIDITY AND VELOCITY TO SETTLEABLE SOLIDS IN 1986.



0.2" category. As demonstrated in Figure 3, a large portion of the observations in this large category would still have high turbidity levels.

A final concern with settleable solids is the notion implied in its name that this parameter measures all particles that will settle out. "Settleable solids", as done in an Imhoff cone, measures only those particles that settle in the cone in one hour. Many smaller particles that would not settle in the one hour time period will eventually settle somewhere. Use of this measurement with placer mining has resulted in the idea that settling ponds that have settleable solids below the detection limit are not releasing particles that might settle downstream. Monitoring during high flow events demonstrates well the amount of sediment that is being deposited during low and normal flows on channel bottoms in streams with upstream placer mining.

<u>Sediment Load and Turbidity Index Load</u>

Sediment load is the estimated total amount of sediment carried by the stream. Table 1 shows the monthly averages at the sites where samples for TSS were taken in 1986. Birch Creek at the Steese Highway Bridge is the furthest downstream site below all mining. It has the largest monthly sediment load averages. In the Birch Creek basin most mining takes place above Crooked Creek above mouth and Birch Creek above Twelvemile Creek. The combined average sediment loads from those two sites should approximate the load at the Birch Creek at the Bridge site. However, the load at the latter site is much greater than the sum of the upper two sites, indicating that last summer much of the lower Birch Creek load was picked up from the channel bottom.

TABLE 1. Sediment loads associated with placer mining monthly average in tons per day

Location	June	July	Aug	Sep
Birch ab 12Mile	420	79.2	40.2	48.3
Birch at Bridge	7270	1450	[1]	567[2]
Crooked ab Mth	1600	268	47.9[2]	101[2]
Boulder nr Steese	2.65	1.89	0.30	0.14
Mammoth at Steese	171	27.3	36.2	65.8

[1] equipment not working.
[2] averages of discrete samples and observations.

The impact of mining on streams in the Birch Creek drainage can be judged by comparing the loads of Mammoth and Boulder Creeks, two neighboring, similarly-sized creeks. Mammoth Creek is mined and drains an area of approximately 42 square miles. Boulder Creek is presently unmined, although has had historical mining, and drains an area of 33 square miles. Boulder Creek drains seventy-eight percent of the area of the Mammoth Creek but has only two percent of the sediment load.

Sediment load is a good measure of pollution from mining during the last three years of data collection because it describes the total amount of sediment being moved by a stream, as compared to TSS which describes the amount of sediment in a standard volume of stream water. The extensive TSS data needed to calculate sediment load was only collected at automated sites during the 1986 summer. Turbidity has been monitored at a number of sites for the past three years and can be multiplied by discharge to compare the amount of turbidity at these sites. Table 2 shows monthly average turbidity index loads (TIL) at the sites monitored for during 1984-86. At most sites affected by mining TIL has decreased each year. The magnitude of the decrease should be compared with the results at the sites unaffected by mining (Bedrock and Boulder Creeks) which show substantial increases. One explanation of this is that non-point source sedimentation increases (evidence from the unmined streams) are masking to a degree the decrease in point source sedimentation (mine effluent). Thus, turbidity from point sources may be decreasing more than is indicated by the monitoring. However, the TIL for unmined streams is so small that only a small fluctuation in turbidity results in a large percentage change. Apparent from Table 2 is that large decreases in TIL in streams affected by mining will be necessary before they are within the TIL ranges of the unmined streams.

Of note is the importance and value of automated samplers and water level recorders for the 1986 monitoring. Use of automated equipment allowed sampling during extreme events and development of a continuous record throughout the summer. The ability to do this is a significant improvement over the collection of many discrete samples and observations as done in previous years. The equipment has not been foolproof - beavers chewed through several transducer lines and intake hoses, a bear attacked a sampler at one location, transducers and batteries failed, and at times the correct buttons were not pushed. However, without the automatic equipment the record would be much less complete and the flood data from 1986 would not have been collected. Any plans for season-long monitoring of placer mining should include the use of automated equipment.

TABLE 2. Turbidity index loads, Birch Creek Basin, 1984-86
Units are NTU-cfs/1000
[m] indicates site is below mining

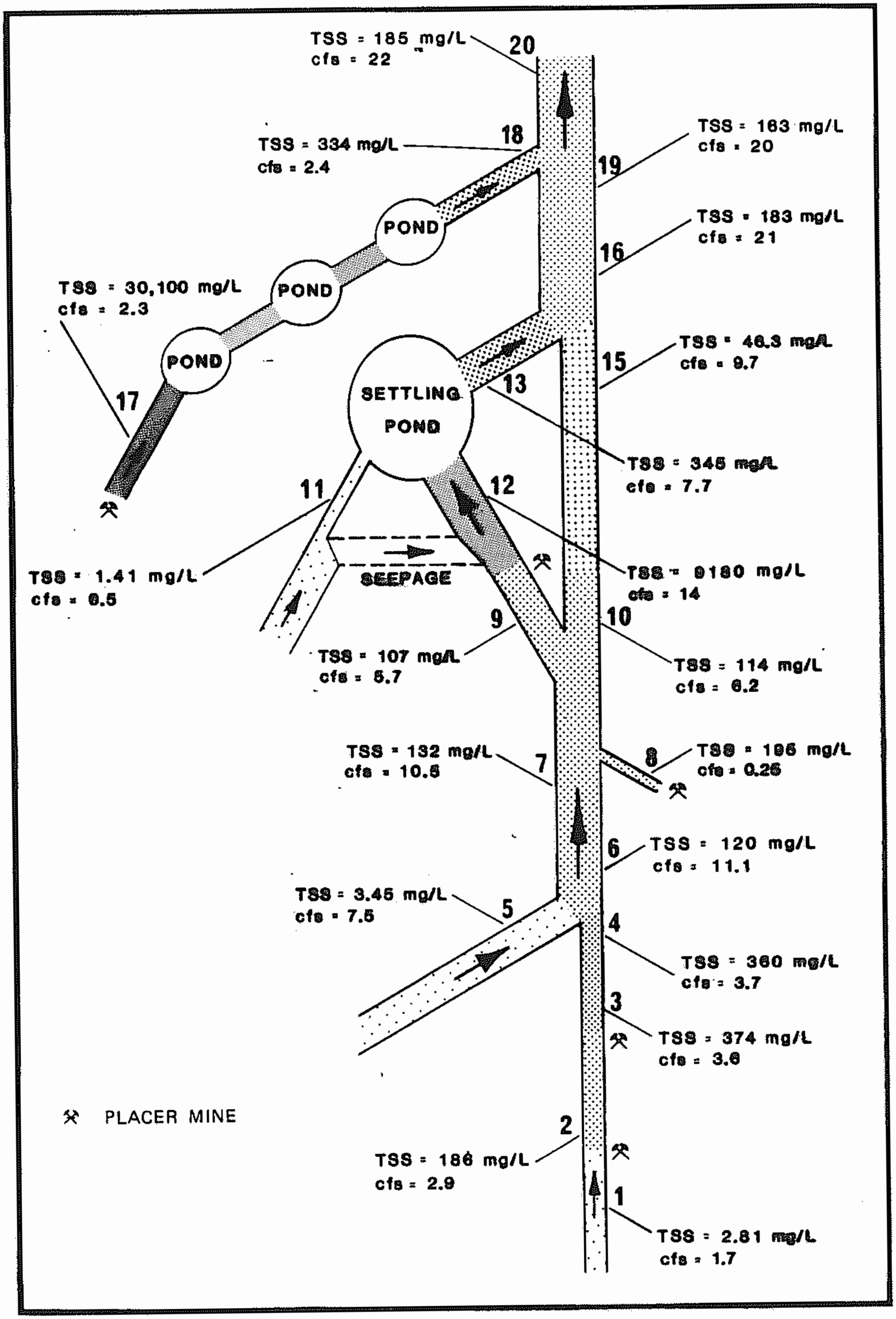
Location	Year	June	July	Aug	Sep	Chng from prv. year %
Averages of discrete observations						
Albert at Steese	86	3.6	0.60	0.002	0.074	
Bedrock at Steese	84			0.002	0.002	
	85	0.025	0.001	0.007	0.005	244
	86	0.016	0.090	0.001	0.005	196
Crooked at Cntrl[m]	84			35.2	36.7	
	85	58.1	43.4	34.6	29.3	-11
	86	28.4	22.2	2.6	193	49
Deadwood at CHSR[m]	84			12.0	7.5	
	85	53.6	11.0	9.0	8.3	-11
	86	1.4	0.9	0.2	0.9	-96
Ketchem at CHSR[m]	84			8.7	0.7	
	85	3.1	6.4	9.7	21.5	234
	86	1.8	0.6	0.2	2.0	-88
Porcupine ab Mth[m]	85		1.7	16.4	23.9	
	86	3.7	2.8	0.5	11.5	-65
Averages of data from automatic samplers except where noted[1]						
Birch ab 12Mile[m]	86	52.8	25.1	16.9	19.2	
Birch at Bridge[m]	85	216[1]	39.3[1]	67.6[1]	68.2[1]	
	86	295	261		15.8[1]	13
Crooked ab Mth[m]	85	73.8[1]	44.4[1]	45.9[1]	30.9[1]	
	86	95.5	28.3	2.6	9.7[1]	-30
Boulder nr Steese	85		0.029[1]	0.009[1]	0.015[1]	
	86	0.13	0.10	0.014	0.013	138
Mammoth at Steese[m]	84			11.8[1]	19.6[1]	
	85	26.7[1]	7.9[1]	10.2[1]	17.2[1]	-13
	86	19.7	8.3	5.8	14.1	-23

Mammoth Creek Intensive Study.

Figure 4 is a schematic diagram showing the results of three days of the Mammoth Creek Intensive Study with graphical representations of discharge and sediment concentrations at various locations in the stream basin. It shows the typical relationships of mine discharge and seepage, stream dilution, and resulting sediment levels, in a stream with several mining operations.

Operations that released less water had smaller impacts on the stream system. The two operations that used recycling contributed less than 10 percent of the total load in the system during steady-state operations. One operation using a large settling pond, but with large water

Figure 4. Schematic diagram of intensive study results



use and tributary inflow into the settling system contributed approximately 65 percent of the load.

If all operations on Mammoth Creek during this study had impacts similar to those of the recycling operations, total suspended solids (TSS) in Mammoth Creek at the Steese Highway Bridge (at the downstream point of this system) would have been in the 50 to 100 mg/l range compared to the average of 185 mg/l during this period. If the reduced water concept was used in all locations in the Birch Creek Basin, turbidity and TSS levels in Birch Creek would be noticeably lower.

The intensive study originated as an attempt to track settleable solids through a heavily mined stream system. Because of the normal-to-low flows in Mammoth Creek and the treatment efforts of the miners, settleable solids levels at all locations, except directly below sluicing, were mostly in the trace range, below the lower detection limit of an Imhoff cone. This illustrates a problem with using settleable solids as a management guideline for managing sediment-laden effluent discharges - samples below the lower detection limit can still have significant and varying amounts of sediment.

The results of the study when compared with season-long observations demonstrate the utility of season-long monitoring. The average sediment load at the Steese Highway site for the study period (11 tons per day) was low compared to the average for the summer (75 tons per day). Much of this difference can be attributed to high flows in June. However, in September when no large storms occurred and flows were normal and steady through the month, sediment load at the Steese Highway bridge site averaged 66 tons per day. For this magnitude of change to have occurred late summer practices must have been different from those observed during the study period.

CONCLUSIONS

We have developed efficient methods for monitoring sediment levels in streams impacted by placer mining. Automatic samplers compositing four samples daily into one bottle give a good temporal range for determining a daily average of turbidity or TSS. Combined with discharge estimated from continuous water level records, a reliable picture of sediment levels can be constructed. Grab samples and observed water levels from neighboring streams enable wider coverage in a particular basin. Our monitoring in the Birch Creek Basin in 1984-86 has demonstrated the seasonal variation of sediment levels, the difference between mined and unmined streams, the effects of floods on sediment levels, the measurement problems with settleable solids, and ways that monitoring could enhance a management program. The Mammoth Creek Intensive Study illustrated how adequate treatment and reduced water use combined with dilution from unmined drainages could result in more acceptable downstream water quality.

The issue of placer mining water quality has become quite political, with deeply entrenched positions held by many people and groups. Data collection efforts, such as ours, will help increase the amount of information available to dispel myths and help direct discussion toward solving the real problems facing the placer mining industry.

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SEDIMENT REMOVAL WITH RECYCLING IN GOLD PLACER MINING OPERATIONS

by Ronald A. Johnson, Jeffrey H. Chapman and Robert M. Lipchak[1]

ABSTRACT

Without effective treatment to remove particulate matter from process waters, gold placer mining operations can result in the discharge of unacceptably high sediment loads to receiving waters. To study the potential of recycling technology to reduce the discharge of particulates, a 2 gpm test loop was used to simulate an actual recycle operation. Two different configurations were tested using paydirt with clay content varying from 2% to 6% with up to 12 recycles being utilized. In all cases, over 90% of the TSS in the feed were removed during each recycle, and the levels of TSS remaining appeared to stabilize after several recycles. However, the recycled water had turbidity levels ranging from several hundred to several thousand NTUs. Hence, additional treatment would normally be required before discharge to Alaskan waters. The configuration utilizing two sedimentation basins at a lower flow rate had effluent TSS an order of magnitude less than the configuration with just one basin.

BACKGROUND

The Alaska placer mining industry was begun by prospectors moving northward into southeastern Alaska from the California gold rush in the 1860s. Just before World War II, Alaska was leading the U.S. in gold production, with a yield of nearly 0.75M (million) ounces in 1940. After a drastic reduction in productivity during World War II and a virtual cessation of dredging during the 1960s, gold mining activity increased considerably during the late 1970s because of increases in the price of gold. In 1981, 0.135M ounces were mined, nearly 10% of the total U.S. production and slightly more than the Yukon production that year (Environmental Protection Service and Canadian Resourcecon, Ltd., 1983; Bundtzen et al., 1982; U.S. Bureau of Mines, Dept. of Interior, 1982). Compared with the 21M ounces produced by South Africa in 1981 (U.S. Bureau of Mines, Dept. of Interior, 1982), the Alaskan contribution to the free world's gold production is small. The value of the gold produced is about 10% of the ex-vessel value of all seafood harvested by Alaskan fishermen (Alaska Division of Budget and Management, 1982), but the impact of placer mining on the economy of Alaska is significant, with around $80 million having been spent by placer miners for labor, goods and services in 1982 (Louis Berger and Associates, 1983). This is about 1% of Alaska's gross product (Goldsmith, 1983).

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Virtually all the Alaskan gold mines are placer mines, meaning the gold is deposited in unconsolidated material, usually gravel. A typical operation involves separating the gold from the less valuable materials by moving the paydirt through a sluice box. As the paydirt is washed, large amounts of suspended material are incorporated into the process water. Even after treatment with settling ponds, substantial amounts of total suspended solids (TSS) and turbidity can be discharged into receiving waters (Johnson, 1984).

Hundreds of papers have been written in the last half century concerning the effects of sediment on hydrologic systems, with many focusing on the impact on aquatic life. A recent and very relevant one is a U.S. Geological Survey review (Madison, 1981). Although only a minority of the reports reviewed dealt with placer mining directly, any land disturbance that introduces sediment into the stream system can provide useful information. Some of the significant physical effects include increased turbidity with reduced light penetration, channel alteration including pool-riffle ratio and scouring characteristics, and changes in stream bottom material including changes in the particle size distribution that can alter the rate of water flow within the gravel bed.

Effects on aquatic plant life include reduced growth of algae and macrophytes because of the loss of photosynthetic activity and a physical smothering of plant life on the bottom. The abundance and diversity of benthic invertebrates are reduced because of the decreased plant life, the fine sediments that clog the animals' feeding apparatus, and the loss of suitable substrate habitat. The community composition will be changed from clean-water species to those more adaptable to higher sediment levels.

Fish life is affected by lessened available food due to production decreases at the lower trophic levels, interference with sight feeding by salmonids, and reduction of pool levels. By increasing the percentage of fines in spawning gravels, increased sediment loads can reduce intergravel flow rates and hence reduce the oxygen transport capacity of the interstitial water, which in turn can greatly decrease survival of fish eggs and fry.

Mining silt deposited on gravel spawning beds during incubation has been shown to be a serious menace to natural propagation (Shaw and Magna, 1943). Timing is crucial: naturally high stream turbidity is limited to those times when storm water causes erosion and when deposition of silt in spawning areas is minimal, but mining silt frequently enters streams at times when the water velocity is unable to carry the sediment in suspension. Thus, while the silt may be natural material, its presence during nonerosion periods results in bottom deposition that is both unnatural and damaging.

The Alaska Water Laboratory studied water quality at mines in six mining districts in Alaska (Alaska Water Laboratory, 1969). Significant populations of fish and/or fish-food organisms were found in clean water above the mining operations but were either absent or much scarcer in the highly turbid waters below the mining operations. In the worst case, a turbidity of 110,000 JTUs occurred just below a stripping operation. A review conducted in 1976 concluded that information specific to placer mining in Alaska is particularly lacking and little research is being supported. The authors concluded that sound evidence existed that TSS levels below 25 mg/L produced no harmful effects on fisheries while 100-400 mg/L was unlikely to support good fisheries (Zemansky et al., 1976).

There is a strong basis for believing that placer gold mining can affect fish reproduction, growth and survival (Alaska Dept. of Environmental Conservation, 1979). Further, streams subjected to unnatural silt loads may require from five to over 20 years to recover once the sediment source has abated (Hall and McKay, 1982). A continuing study supported by the EPA has the confluence of a mined and unmined fork of Birch Creek as its primary area for field work (Bjerklie and LaPerriere, 1985; LaPerriere, 1983). It has been found that both SS and TSS are much higher in the mined fork and that algal productivity is much higher in the unmined fork. Invertebrate density is much higher in the unmined fork; very few organisms comprising very few taxa can be found in the stream receiving placer mining effluents. Caged fish from the mined fork had reduced fat tissue around their internal organs compared with the control caged fish.

In the Yukon Territory, 40 mined sites were studied that had been abandoned between 1915 and 1980; streamflows ranged from .1 to .5 m^3/sec (Singleton et al., 1978). Physical characteristics such as velocity and substrate characteristics were the greatest limitations to grayling habitat recovery. Restoration of physical habitat of placer-mined wide valleys to control levels required 29 to 72 years, and restoration of the water quality 20 years. No recovery trends were noted in the narrow valleys. The lack of channel stability and placid flow areas were the most limiting factors to habitat recoveries.

In the rationale for proposed TSS standards for the Yukon Territory (Environment Canada Environmental Protection Service, Dept. of Fisheries and Oceans, 1983), numerous studies were quoted demonstrating the significant effect that small increases in sediment can have on salmon egg and fry survival. For instance, a 12% increase in TSS for the Coquitlam River in British Columbia led to a 55% decrease in salmon egg survival (Langer, 1980); elsewhere, TSS concentrations of 100 mg/L reduced coho salmon feeding by 45%, with feeding ceasing altogether when the TSS was greater than 300 mg/L (Noggle, 1978). The summary implies that the greatest danger posed by sediment in streams is not its acute affects but the more subtle effects that can interfere with an organism's capacity to survive.

REGULATORY STATUS

The Federal Water Pollution Control Act amendments of 1972 (P.L. 92-500) provided for the establishment of effluent limitations for certain types of industrial operations, including mining, and water quality standards for natural surface waters into which effluents are discharged. Section 301 of this act required the establishment of technology-based effluent limitations on industrial discharges in accordance with certain guidelines. These are specified in permits under the National Pollution Discharge Elimination System (NPDES) of Section 402. The Clean Water Act amendments of 1977 (P.L. 95-217) altered some deadlines established by P.L. 92-500 and established July 1, 1984, as the date by which all industries must meet Best Conventional Technology (BCT) for conventional pollutants (including TSS) and Best Available Technology (BAT) for toxic pollutants. Establishing just what is meant by BCT or BAT for gold placer mining is the crux of the problem in Alaska.

Alaska had certified about 540 permits (as of the spring of 1986) setting a SS limit of .2 mL/L instantaneous maximum. In addition, the effluent limitation for turbidity must be less than 5 NTUs above background and no greater than .05 mg/L for arsenic. These latter two limitations are based on Alaska's water quality standards for rivers and streams. The Alaska Department of Environmental Conservation (ADEC) emphasized enforcement of only the SS limits for the summer of 1986 with field monitoring focused on 31 priority streams.

In November 1985, the proposed national requirements for placer mining discharges were published in the Federal Register (Federal Register, 1985). For all operations processing less than 15.28 m^3/d (20 cu yd/day) no permit is required. For those with 15.28 to 382 m^3/d (20 to 500 cu yd/day) the effluent limitations are 0.2 mL/L SS and 2,000 mg/L TSS. Complete recycling of process waters is required for operations processing greater than 382 m^3/d (500 cu yd/day). About 55% of Alaska's mines requiring permits fall into the category of 15.3 to 382 m^3/d. These rules, perhaps in an altered state, become final in October 1987.

During the summer of 1986, the U.S. Bureau of Mines and the U.S. Environmental Protection Agency (EPA) field tested polyethelyne oxide (PEO) at several mines in Alaska. Preliminary indications are that turbidity levels were reduced by factors of 100 at one site but no economic evaluations are now available. Testing performed by Northern Testing Labs in Fairbanks at the Esperanza Mine site revealed very high particulate removals at one field site with eight combinations of a cationic coagulant plus an anionic flocculant. In the optimum cases, the supernatent turbidity was less than 5 NTU with the influent turbidity ranging from 1,200 to 13,400 NTU. High removals of TSS, SS and As were also achieved. An economic assessement indicates a total daily cost of $225 for the flocculant system treating 150 gpm. The total wastewater treatment system cost is $534/day for a 100 day season. The corresponding total process flow that is recycled is 1,500 gpm (Pollen, 1986).

RECYCLE TEST LOOPS

To provide data on the ability of recycling technology to achieve these permit stipulations, we constructed two test loops at the University of Alaska-Fairbanks. A parallel purpose was to study the properties of the recycled fluid to assess its suitability as sluicing water. By using this laboratory-scale facility, we were able to perform tests much more economically than by conducting full-scale testing in the field. Our results provide a more realistic simulation of field conditions than quiescent settling conducted in a batch mode.

The first test loop (Fig. 1) consisted of a vibrating feeder, a shaker with drain and tailings chute, a 1.11 m^2 (12 ft^2) settling tank, and a recycle line with pump and hydrocyclone. A plan view is essentially the left hand third of Figure 2 coupled with Figure 3. The feeder discharged the prescreened paydirt onto the shaker apparatus that contained a 1.70 mm (12 mesh) screen mounted in a steel box sloping at about 25° with the horizontal. The washed oversize material (>1.70 mm) (+12 mesh) was removed as tailings via the tailings chute while the underflow flowed into the drain and then into the settling basin. When filled to a depth of 17.8 cm (7 in) the basin volume was 196 L (52 gal). The basin overflow was drawn through a 1.90 cm (3/4 in) intake line by a 1.1 kw (1.5 hp) pump and finally discharged through 1.59 mm (1/16 inch) holes drilled in spray bars. The latter generated spray jets allowing the paydirt to be washed. A 25 mm cyclone (Doxie) in the recycle line allowed us the option of conducting some performance tests with this device.

After two series of tests were run with the recycle loop, it was modified as shown in Figure 2 by adding an additional settling chamber with a surface area of .44 m^2 (4.75 ft^2) upstream of the original basin. This basin had a wetted volume of 132 L (35 gal) and served to remove the bulk of the solids. In addition, baffles were added in the original (second) basin. They were constructed from 15 cm long by .5 cm wide strips of rubber hanging vertically into the water, aligned across the basin perpendicular to the direction of flow. Moreover, the 25 mm cyclone was replaced by a 10 mm unit (each unit was manufactured by Dorr Oliver). The spray jets were altered by using a nozzle instead of drilled holes. Three different runs were performed with this modified test loop.

The paydirts utilized for all five runs were obtained from a gold placer mine near Fairbanks and were initially sieved to remove all material larger than 6.4 mm (1/4 inch). The particle size distributions corresponding to the feed material for each of the five runs appear in Figure 4. Runs 1 and 2 were performed with feed soils of 2% clay, Runs 3 and 4 with 4% clay and Run 5 with 6% clay.

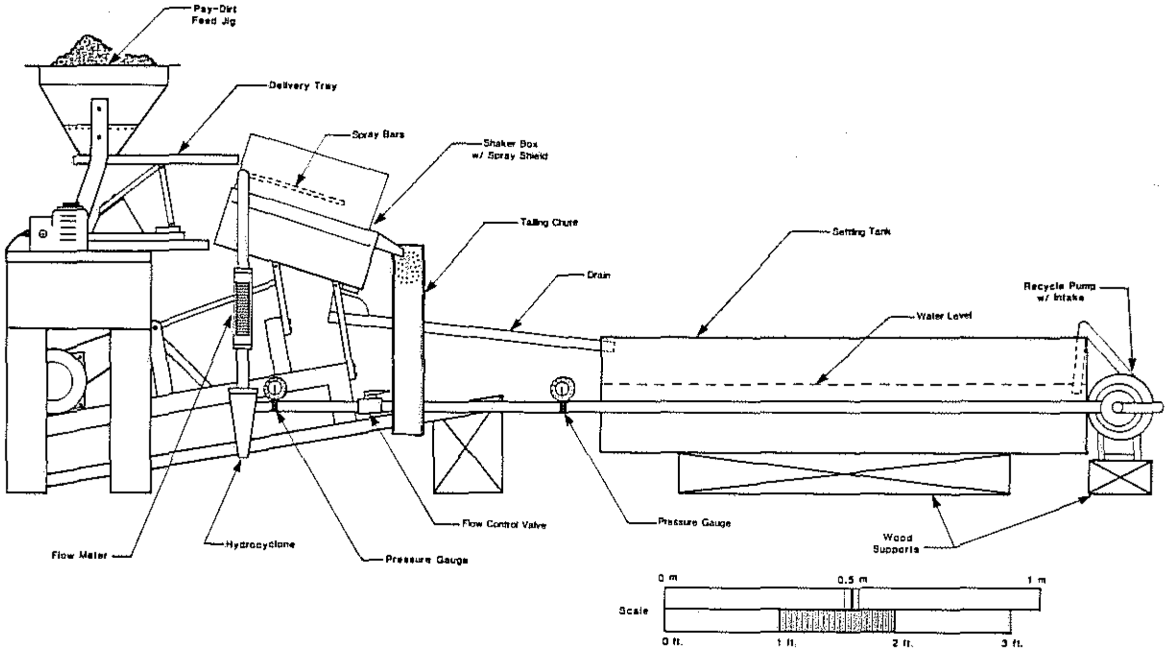

Figure 1. Schematic of original test loop (side view).

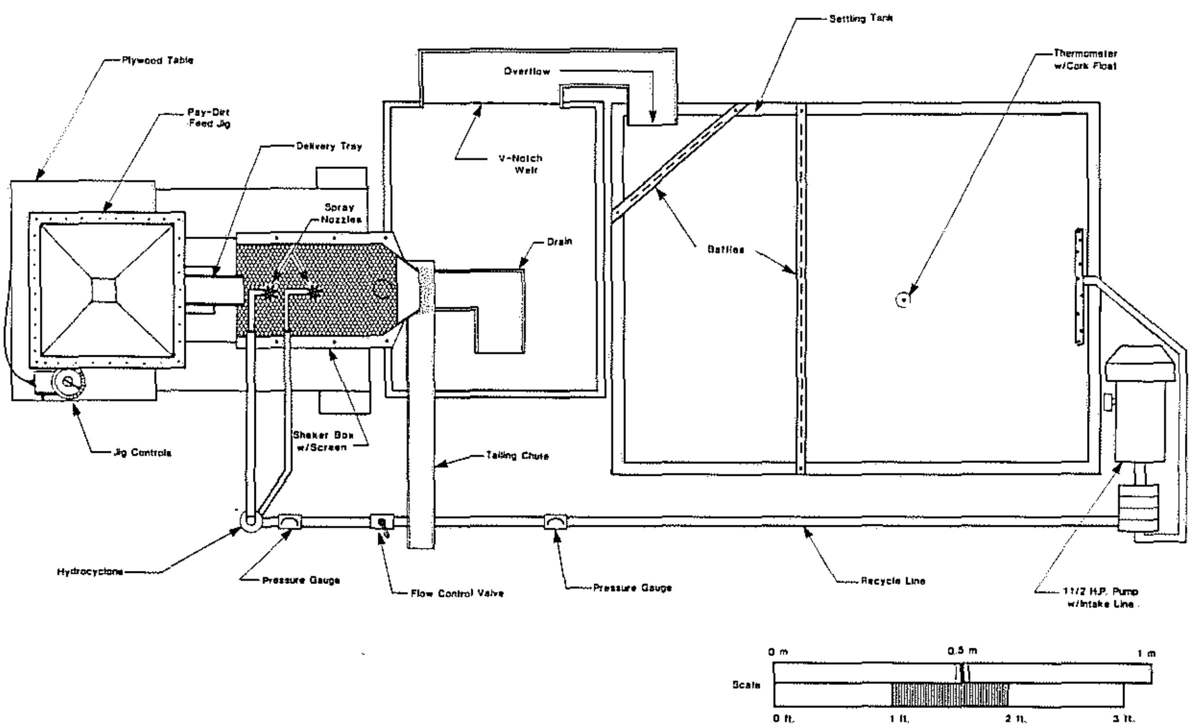

Figure 2. Schematic of modified test loop (plan view).

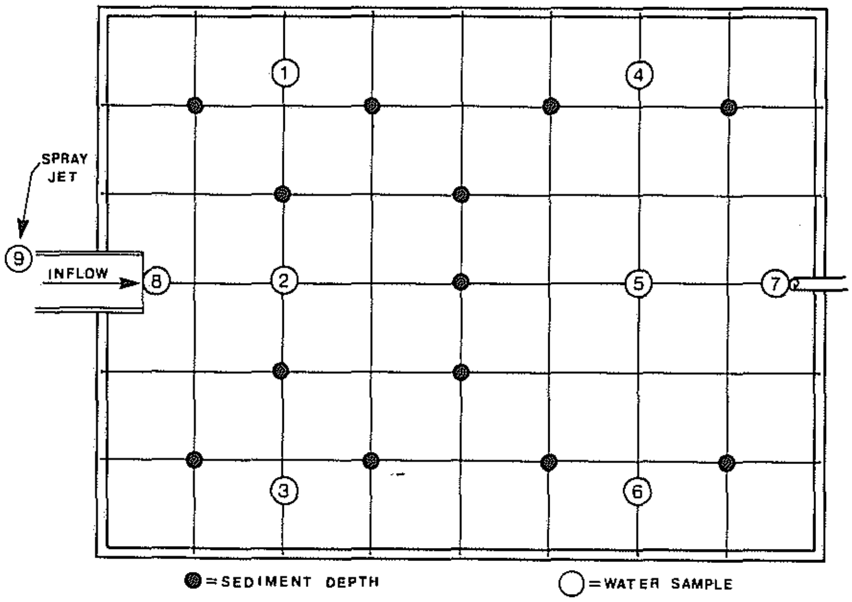

Figure 3. Sampling locations for original test loop in sedimentation basin.

TEST MATRIX

A summary of the critical operational parameters for the five test runs appears in Table I. The recycle flow rate was held constant at .13 L/s (2 gpm) for the first two runs and .063 L/s (1 gpm) for the last three runs, while the water duty varied from 68,500 (Run 1) to 25,900 mg/L (Run 2) (.21 to .08 yd^3 paydirt per 1,000 gal washwater). The water duty for Runs 3 to 5 was about .17 yd^3/1,000 gal. Some of this material was removed as tailings (and some rapidly settled to bottom upon leaving drain) so the measured concentration of TSS near the inflow ranged from 2,840 to 22,100 mg/L. These (the latter) concentrations are below average to average for sluice effluents for Alaskan operations employing recycling (Shannon and Wilson, Inc., 1985). The total duration of each run ranged from 2.6 to 8.7 hours with the number of recycles varying from 4 to 12. The residence time in the larger basin was either 26 or 52 mins and 35 mins in the smaller tank.

Cyclone tests were conducted during several periods as part of the overall testing but no attempt was made to improve the overall system performance with the cyclone. Instead, the efficiency of each cyclone was measured for removal of SS, TSS and turbidity. The cyclone was tested after the recycling tests were completed for the first two runs and was operated continuously through the second half of the last three runs. Both the overflow and underflow were returned to the spray jets for the last three runs. Hence, the overall routing of the flows was not affected by the cyclone.

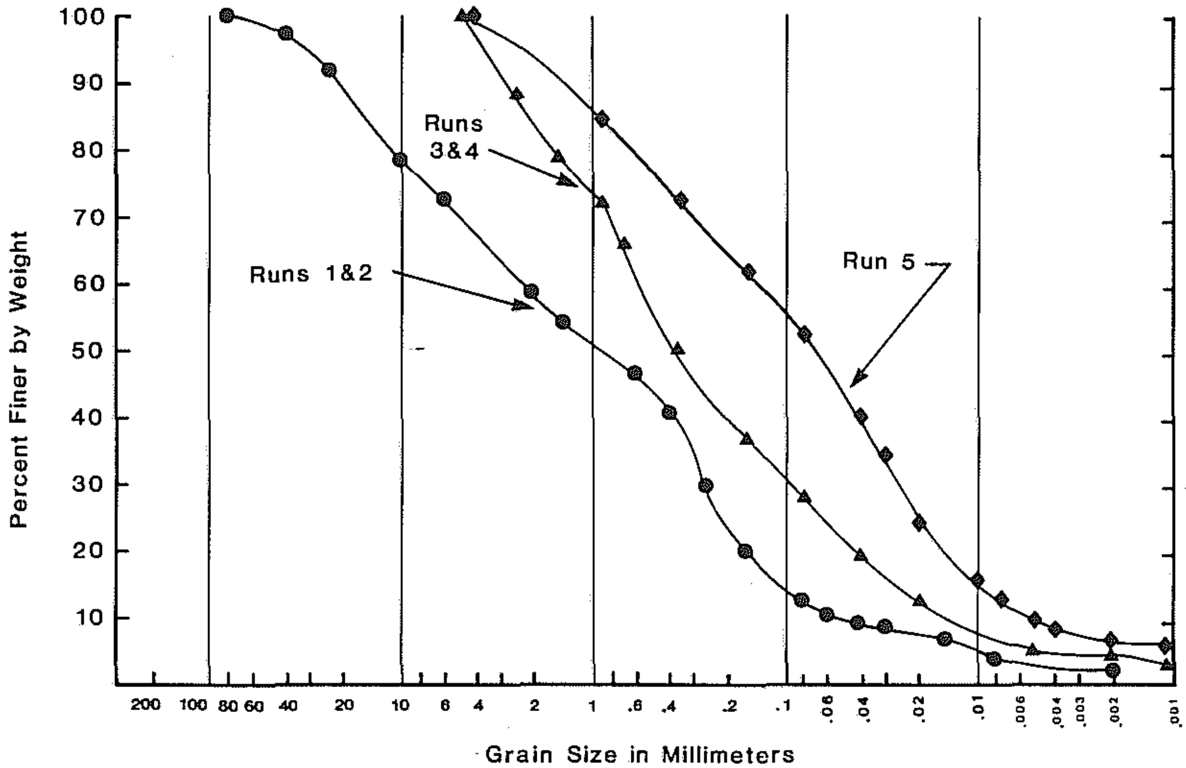

Figure 4. Size distributions of paydirts tested.

TABLE I. Test Matrix.

Run No.	Number recycles	Flow rate (gpm)	% clay in feed	Test duration (hrs)	TSS removal efficiency per cycle (%) (measured)	(predicted)
1	6	2	2	2.6	94	94
2	12	2	2	5.2	91	94
3	4	1	4	5.8	99.2	93
4	6	1	4	8.7	99.0	93
5	4	1	6	5.8	98.2	89

TESTING PROCEDURES

Water samples were collected in 30 mL vials at the locations shown in Figure 3 for the first run with eight samples taken during each sampling period (after each recycle and half way through the first and second recycles). Samples were collected after the first, second, third, fifth, seventh and the ninth through twelfth recycles for the second run. Samples were collected at least as often as once per recycle for the last three runs from the recycle line and for effluents from the first and second basins.

One-liter samples for SS and viscosity were also taken at the midway through and at the end of each of the last three runs. During the periods of cyclone testing, samples of the feed overflow and underflow were taken with the sample size being a minimum of 30 ml. Analyses for TS, SS, TSS and turbidity were performed according to Standard Methods (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1985).

Two measurements of sediment buildup on the settling tank bottom were taken during Run 1 and three during Run 2 with more detailed measurements at the conclusion of each run. Sediment profiles in the first basin were also taken at the end of Run 3 and the masses of sediments deposited measured at the end of each run.

The particle size distributions for the feed material was determined by dry sieving that larger than 75μm (200 mesh). The material smaller than 150μm (100 mesh) was then wet sieved down to 38μm (400 mesh). For the very fine material (less than 62μm), a pipette analysis or hydrometer was used to determine particle size distributions. The overlap between the dry and wet sieving and between the wet sieving and pipetting served as a check on the methodology. In addition, a Lietz vario-orthomat photomicrography system using normal incident light and a Carl Zeiss MC-63 photomicroscope were utilized to obtain more details for particle size distributions for some of the water samples. Viscosity was measured using a Brookfield rotating spindle viscometer.

RESULTS AND DISCUSSION

Detailed results for the variation of TSS with number of recycles appear in Figures 5 and 6 and for turbidity in Figure 7. Data do not appear for Run 3 because they are almost the same as for Run 4. The only difference between the two runs is that Run 4 lasted longer. Results for Run 1 (not plotted) reveal similar trends as for Run 2. Depth profiles of sediment for Run 2 appear in Figure 8. Similar profiles occurred in the first basin for the other runs. A comparison between observed and predicted TSS removals appears in Table I and summaries of results for the hydrocyclone tests in Table II. The variations in the influent values of TSS and turbidity are due largely to an unsteadiness in the feed rate of solids. These values are not

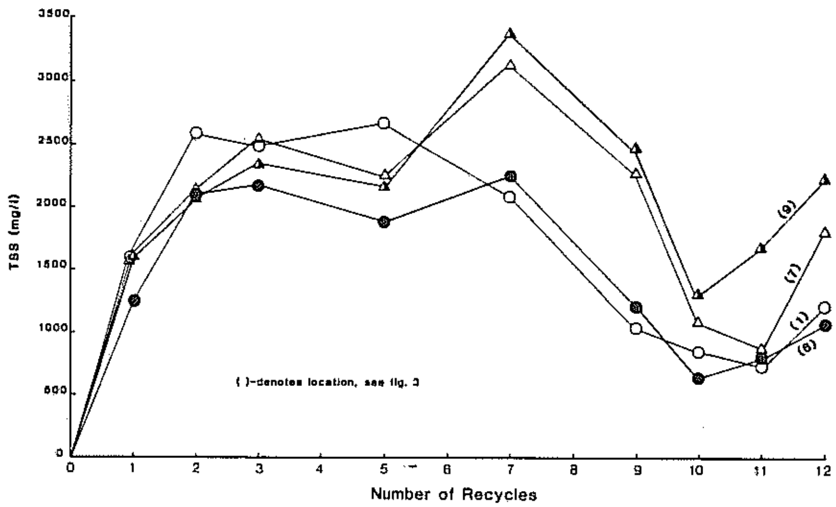

Figure 5. TSS levels vs number of recycles for Run 2.

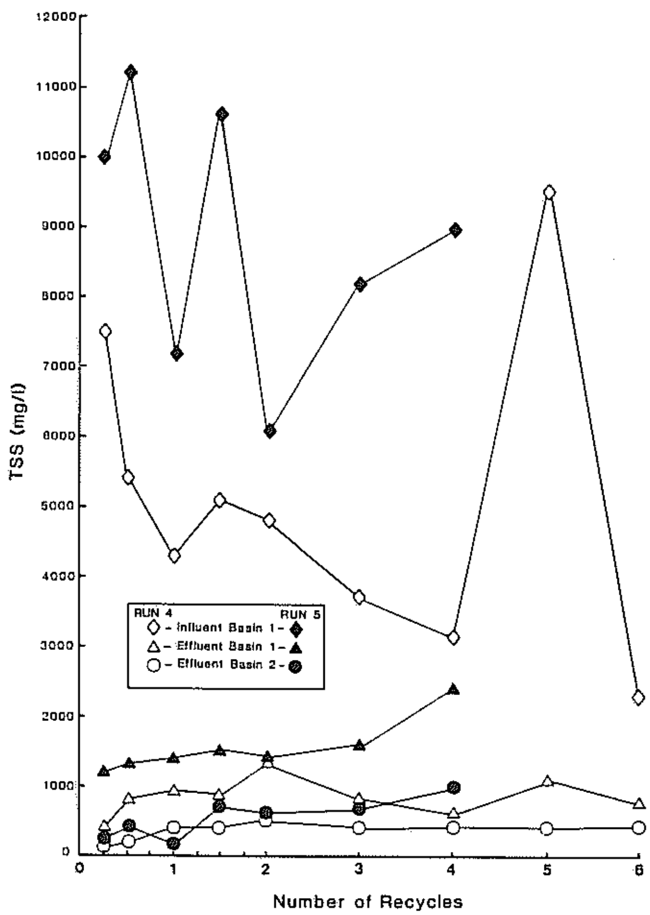

Figure 6. TSS levels vs number of recycles for Runs 4 and 5.

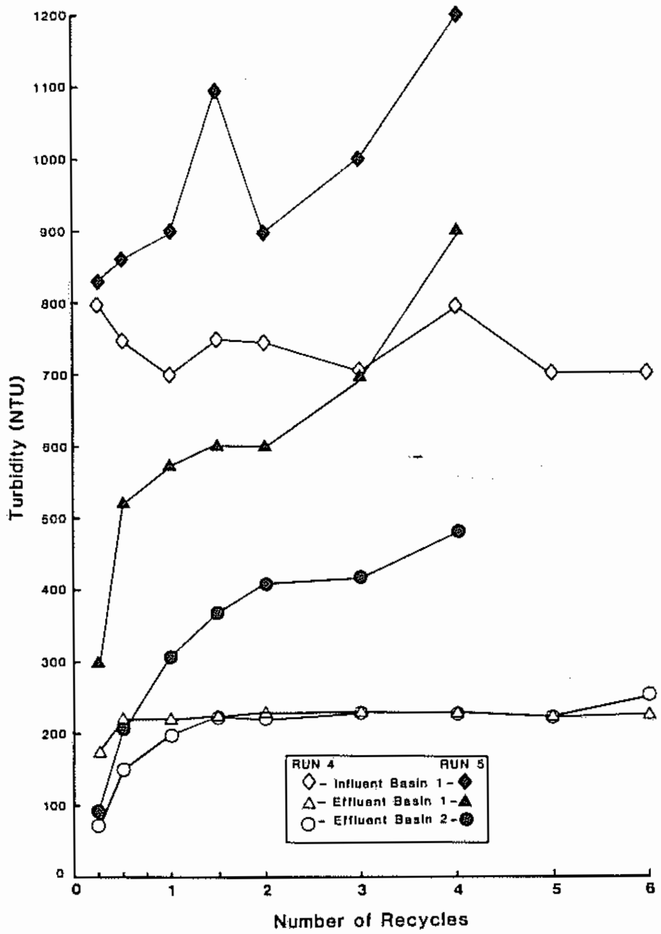

Figure 7. Turbidity vs number of recycles for Runs 4 and 5.

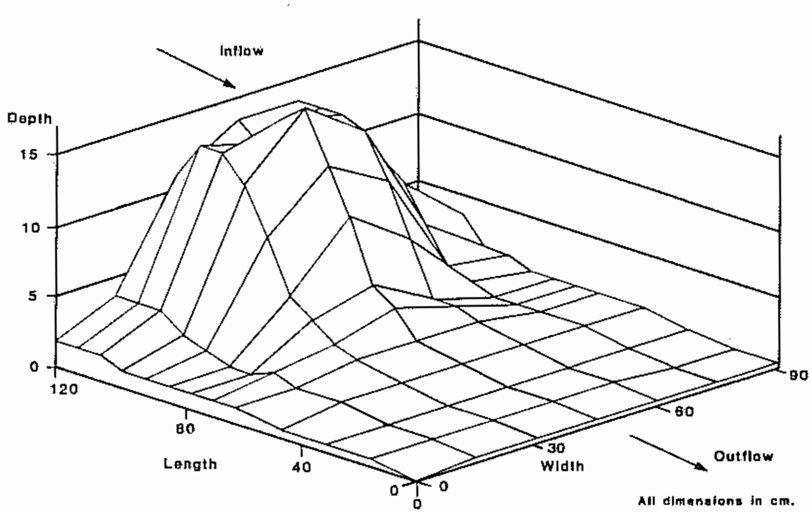

Figure 8. Sediment depth profile for Run 2.

TABLE II. Hydrocylone efficiencies.

Run No.	1	2	3	4	5
SS removal (%)	100--				
TSS removal (%)	35	40	47	64	76

explicitly plotted for the first two runs. Note how these fluctuations are damped by the time the flow reaches the effluent. Such unsteadiness, although not originally planned, does simulate the way paydirt is fed into the sluice box at an actual placer mine. Although error bars are not shown on the data, when TSS samples were collected in triplicate for a mixture of bentonite in water, they indicated a coefficient of variation less than 2%.

An expected result of the sediment profile plots is the large mound forming below the inlet drain. A depression in the center of this mound was observed to contain a high percentage of larger sized particles. There was an absence of sediment near the pump intake for Run 1 resulting from a single intake hose entraining sediment from the bottom. This entrainment is also manifested in the TSS near the pump intake (location 7) being higher than at locations (1) or (6) (Fig. 5). This led to our altering the pump intake line to a "T" shape for Run 2 that resulted in a more uniform sediment depth near the outlet from the second basin and less disturbance of the sediments. Hence, the TSS levels at location 7 are less for Run 2 than for Run 1. For Runs 3 through 5, the second basin had sediments uniformly distributed over its bottom at a depth less than .5 cm. This contrasts sharply with the one-basin system or the first basin in a two-basin system. At least 97% of the solids removed from the process water during these runs were left in the bottom of the first basin. This certainly illustrates the advantage of using two ponds in series in the field with baffling and recycling from the second pond if one's goal is to produce the cleanest recycle water. This minimizes the possibility of entraining solids from the sediment into the recycled water and is evident in the lower effluent TSS levels for Runs 3 through 5 (Fig. 6) and reflected in the higher measured TSS removal efficiencies (Table I). The latter represent the TSS removal per recycle.

If one used the TSS level taken near the inlet to the first basin (Fig. 6) to infer sediment loadings on the system, one would underestimate the loading. In fact, the actual loadings obtained from weighing the sediment actually deposited are from 5 to 18 times that inferred from TSS readings. This difference is caused by the heavier particles leaving the intake channel rapidly falling to the bottom of the basin and to the bottom of the sampling vials. The samples taken toward the end of each run were collected to one side of the intake channel and, hence, did not incorporate the heavier particles.

Similarly, in extracting a suspension from the sampling vials for filtration, it was very difficult to extract the heavier particles. Sediment loadings in the field that are estimated from influent TSS values probably underestimate the loadings.

The measured efficiency of the second basin in removing TSS for Runs 3 and 5 was around 80%. This is less than the overall system efficiency because the particles entering the second basin were those in the silt size range and smaller. The SS levels in the recycled water at the end of each run were around 1 mL/L. If a portion of this stream were to be discharged to receiving waters, further treatment would be required.

To ascertain the utility of conventional sedimentation theory to predict the performance of these sedimentation basins in removing particulate matter, Equations 1 through 3 were used to predict removal efficiency. The particle settling speed for spheres

$$V_S = \left[\frac{4g}{3C_D} (\varepsilon-1)\ d\right]^{1/2} \tag{1}$$

where g is the acceleration due to gravity, C_D is the drag coefficient based on frontal area, ε the specific gravity, and d the diameter of the settling particle. The drag coefficient (Weber, 1972)

$$C_D = \frac{24}{Re_d} + \frac{3}{Re_d^{.5}} + .34 \tag{2}$$

where $Re_d = V_s d/\nu$ with ν being the kinematic viscosity of the water. It was found to remain between 1 and 1.2 centistokes during all the laboratory tests. For heterogeneous particles at the basin inlet, the total removal fraction

$$R_T = (1-X_o) + \sum_{i=1}^{N} \frac{V_{si}}{V_o} \Delta X_i \tag{3}$$

where $V_o = Q/A$ is the surface overflow rate (SOR), Q the flowrate into the basin, A its surface area, X_o the fraction of particles having settling speeds less than V_o and ΔX_i, the mass fraction of particles settling with a speed of V_{si}. Of course, Equation 1 reduces to Stoke's Law for Re_d <<1. Since ΔX_i is determined from the paydirt entering the settling basin(s), it does not incorporate effects of coagulation.

Equations 1 through 3 together with information on particle size distributions for the paydirt were used to predict removal efficiencies of TSS for Runs 1 through 5. More specifically, V_o was set equal to the SOR for the single basin for Runs 1 and 2 and for the second basin for Runs 3, 4 and 5. The latter is justified by assuming the second basin (being larger) would be capable of removing all the solids that the first basin removed anyway according to ideal settling theory. As an example, the SOR = V_o was 4.9 m/d for Run 4 with the particle size distribution given in Figure 4. From Equations 1 and 2, a particle of diameter 8.6×10^{-4} cm would settle at this speed. Hence, ideally all particles larger than 8.6×10^{-4} cm (about 92% according to Fig. 4) would be completely removed. This corresponds to $X_o = .08$ in Equation 3. The additional 1% removal is calculated from the ΔX_i terms in Equation 3 representing those particles incompletely removed. The measured values for ν and ε are .012 cm^2/s and 2.76, respectively. This removal efficiency, of course, is for one recycle corresponding to a detention time of 52 mins in the larger basin.

The measured removal efficiency (per recycle) is calculated from

$$\eta = 1 - C_e/C_o \tag{4}$$

where C_e and C_o are the average values for TSS in the effluent and feed respectively over the entire test. The former is calculated from data appearing in Figure 6 and the latter by dividing the mass of sediment deposited by the total volume of water processed during all recycles plus C_e. The latter (C_e) represents that portion of the influent TSS not being removed. For Run 4, C_e = 399 mg/L and C_o = 40,156 mg/L.

In all cases, both the predicted and measured removal efficiencies per cycle for the entire system were greater than 89% (Table I) and the measured efficiency for the two-basin system was over 98%. These high removal efficiencies are related, of course, to the relatively low SORs of 9.8 m^3/m^2d (240 gpd/ft^2) for the first two runs and 4.9 m^3/m^2d (120 gpd/ft^2) for the last three runs for the second basin. The latter corresponds to settling speeds of particles of around 9μm in diameter. Since over 87% of our feed material was comprised of particles above this size, we would expect these particle size fractions to be completely removed. For the two-basin system, TSS removal efficiency decreased as clay content increased. Here, as our operational definition of measured TSS removed, we have used the mass of sediment deposited in the settling basins.

From limited photomicrographic data of particles leaving the first basin, it appears that around 60% of the particles are greater than 10μm in size. These should be completely removed in the second basin according to the above predictive model. About 30% are less than 5μm and should not be completely removed. Hence, the measured removals around 80% in the second basin appear reasonable. But, we don't have enough data to quantify this further.

The cyclones were very effective in removing the larger particles as indicated by the negligible SS levels and by the photomicrographs of cyclone overflow. The cyclone overflows indicated no particles larger than about 10μm. This is consistent with manufacturer performance specifications. However, there were enough sub 10 micron particles to produce turbidity levels of several hundred NTUs in the overflow. Hence, neither cyclones by themselves nor settling ponds can meet Alaskan water quality standards for turbidity. The feed flow rates were about .126 L/s (2 gpm) for the 25 mm unit and .063 L/s (1 gpm) for the 10 mm unit. The TSS removal efficiencies (Table II) were greater for the smaller cyclone which is expected.

Levels of TSS and turbidity in the effluent did not keep on increasing after about two recycles. As discussed previously, much of the fluctuations is due to unsteady feed rates. The values after several recycles were higher for Run 5 containing 6% clay than Runs 3 or 4 containing 4% clay. This shows the importance of paydirt composition on equilibrium solids levels. The levels were less than those normally found in the field for recycle intake water for Alaskan operations employing recycling. Recent data indicate average TSS levels ranging from 713 to 8,163 mg/L (Shannon and Wilson, Inc., 1985). The measured viscosity was equal to that of tap water at the same temperature. Hence, neither the performance of settling basins nor the recovery of gold in the sluice box should suffer because of viscosity increases associated with recycling.

If no flocculation were occurring, one would expect the TSS levels to increase with the number of recycles. Data presented in Figures 5 and 6 show this not to be the case. To estimate the amount of required flocculation, we have plotted the difference between total solids and total suspended solids for Run 4 (Fig. 9). The curve labelled "Predicted" was constructed by assuming all the paydirt less than 1 micron in diameter plus the background level due to the laboratory water would end up in the water column with no coagulation. The measured difference represents essentially the colloidal plus dissolved matter and is found not to increase with time. It is calculated from particles passing through a .45μm glass fiber filter. If flocculation were not occurring, we would expect the difference to increase with time as indicated by the curves labelled "Predicted." The fact that this increase does not occur leads one to suggest that flocculation is occurring. This phenomenon is also a likely explanation for the measured TSS removal being larger than the predicted. We should note that approximately 300 mg/L of the measured TS-TSS value can be attributed to the hardness of the laboratory water used in the runs. These hardness ions may have contributed to colloidal destabilization and, hence, enhanced coagulation.

Over 90% of the particles in the overflow at the ends of Runs 1 and 2 were less than 30 microns. For the last three runs, 75% of the particles were finer than 38μm in the overflow from the first basin and all were finer than 25μm in the overflow from the second tank. Generalized flow patterns for the first two runs obtained from fluorescein dye tests appear in Figure 10. These patterns indicate the potential for flocculation. Corresponding times for short circuiting are about 7% of the average detention time. If this time is used (corresponding to an axial velocity of about 1 cm/s), one would predict particles must be larger than 40μm to be completely removed in the settling basin. Similar observations for Runs 3

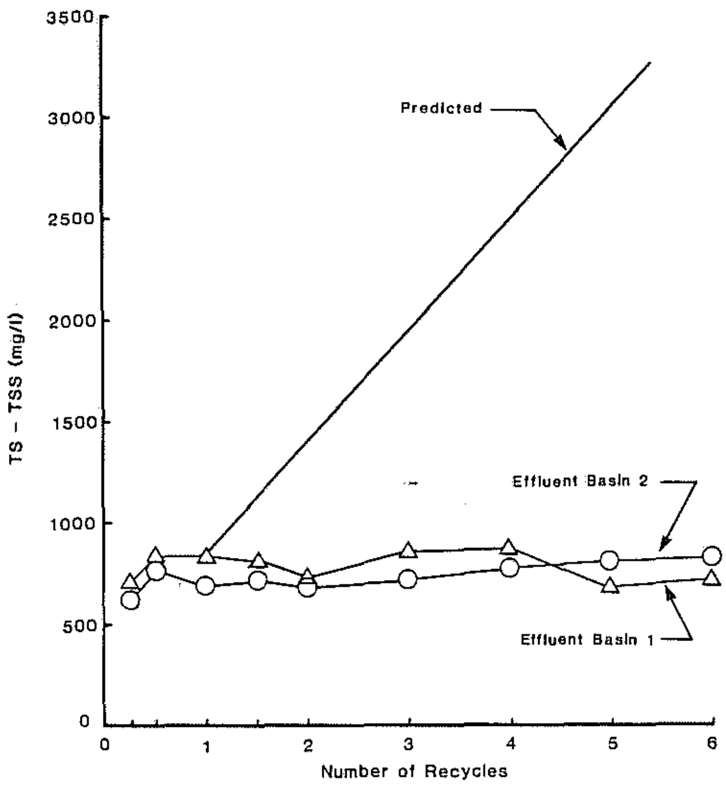

Figure 9. Predicted (assuming no coagulation) and measured levels of colloidal plus dissolved matter vs number of recycles for Run 4.

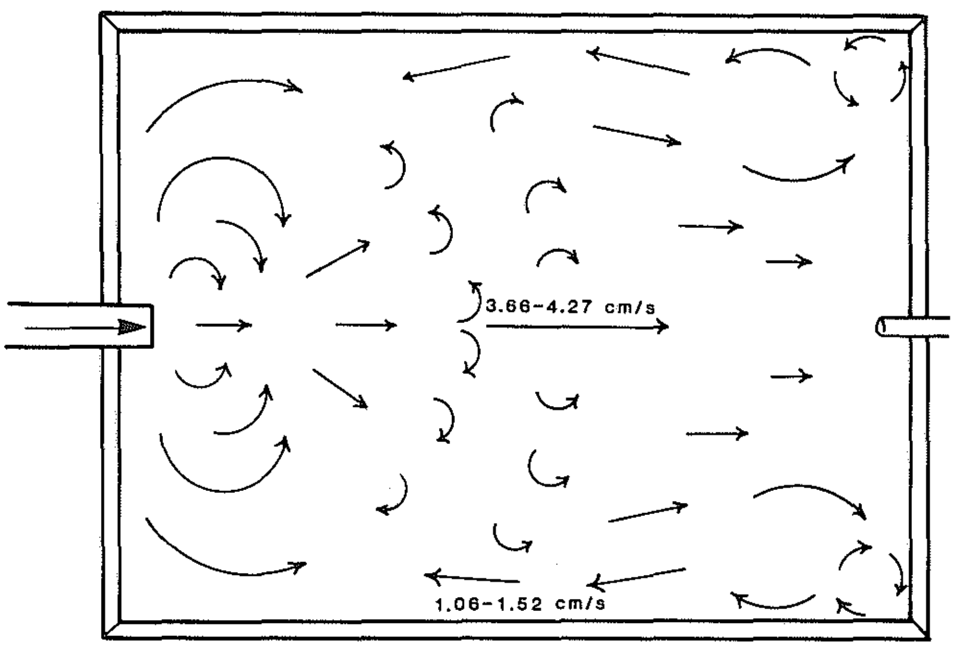

Figure 10. Observed flow patterns in sedimentation basin for Runs 1 and 2.

through 5 indicate a measured axial speed due to short circuiting of about .30 cm/s. The corresponding particle size for complete removal is about 20μm. Each of the axial speeds is much too small to initiate scour of the sediment according to available predictive tools (Camp, 1946) and this is consistent with our observations. Both of these calculated removal sizes correspond to observations of the largest particles in the basin overflow. The lower short circuiting speed for the two-basin system is consistent with both a lower SOR and a better flow distribution into the inlet of the second basin plus baffling. The use of baffles in actual mining operations would both minimize short circuiting and also reduce wind-generated turbulence. The latter can keep fine particles in suspension and, hence, prevent their removal. The Reynolds numbers here based on hydraulic radius (around 100) are an order of magnitude less than those occurring in the field. This plus the possibility of winds in the latter case makes the use of baffles especially desirable. The SORs occurring in the laboratory loop are an order of magnitude greater than those occurring at the field site where the paydirt was obtained. It is noteworthy that the maximum size of solids found in the final effluent at the field site was in the range of 20μm to 35μm (Shannon and Wilson, Inc., 1985). These slightly larger particles in the field than in Runs 3 and 5 could be related to the larger turbulence levels in the field countering the lower SORs there. Each of these, of course, is an important parameter for settling tank performance (Yee and Babb, 1985).

CONCLUSIONS

The implications of these results regarding settling basin performance and recycling for treatment of the process waters in an actual recycling operation are severalfold. First, it appears unlikely that recycling will create significant increases in viscosity. This is a positive result for gold recovery. Second, TSS and turbidity did not continually increase with the number of recycles. This indicates some kind of naturally occurring coagulation is present which can enhance the performance of a settling basin. Third, the use of two settling ponds in series at a lower SOR reduces the TSS levels in the effluent compared with just one pond. This appears to be related to both the lower SOR plus a reduction in short circuiting. This is beneficial both for 100% recycle applications and for the case of a partial discharge to receiving waters. Fourth, cyclones can lead to appreciable reductions in SS but do not result in turbidity levels low enough to allow Alaska water quality standards on turbidity to be met. Fifth, one must be careful in using measured TSS values for process water in the inflow region of the initial settling basin to infer sediment loadings for settling ponds as the former tend to underestimate sediment loadings.

ACKNOWLEDGMENTS

Credits

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RELATIONS AMONG LITHOLOGY, SEDIMENT PRODUCTION AND DRAINAGE DENSITY IN HOSEANNA CREEK BASIN NEAR HEALY, ALASKA

by Stephen Wilbur and Theodore Clarke[1]

ABSTRACT

A program designed to measure suspended sediment variations from sub-basins within the Hoseanna Creek watershed was undertaken to determine the effect lithology has on sediment production, erosion rate, and drainage density. Two years of data reveal that areas underlain by poorly consolidated sand and gravel formations are yielding as much as 50 times more sediment than the areas underlain by a more resistant schist. The drainge density associated each lithology reflects these higher erosion rates.

INTRODUCTION

The Hoseanna Creek watershed in central Alaska is underlain by three different lithologies that erode at very different rates, and therefore the basin provides an opportunity to observe lithologic control on erosion. The basin, located on the north flank of the Alaska Range between Fairbanks and Anchorage, is in a discontinuous permafrost region. It is 124 km^2 in area and trends east-west parallel to the main structural grain of the region. Hoseanna Creek empties into the northward flowing Nenana River about 8 km north of the old Healy townsite (Figure 1).

Discharge and total suspended sediment were measurements from 14 of the 26 sub-basins within the Hoseanna Creek watershed began in July of 1986. Sediment production rates for each sub-basin were computed from data collected through August 1987. In addition, drainage densities were determined for each lithology. Drainage density is the total length of stream channel per square kilometer of area (km/km^2). Differences in drainage densities are taken as an indication of differences in long term erosion rates. For example, well vegetated stable slopes commonly have fewer drainage paths than a highly incised badland. Lithology was then compared to sediment production and drainage density to determine how lithology affects present day sediment production and the long-term effects of erosion.

LITHOLOGIC DIFFERENCES

Three principle lithologies occur in the Hoseanna Creek watershed (Figure 2). The oldest lithology is a Precambrian schist informally known as the Birch Creek schist (Wahrhaftig, 1970). Overlying the

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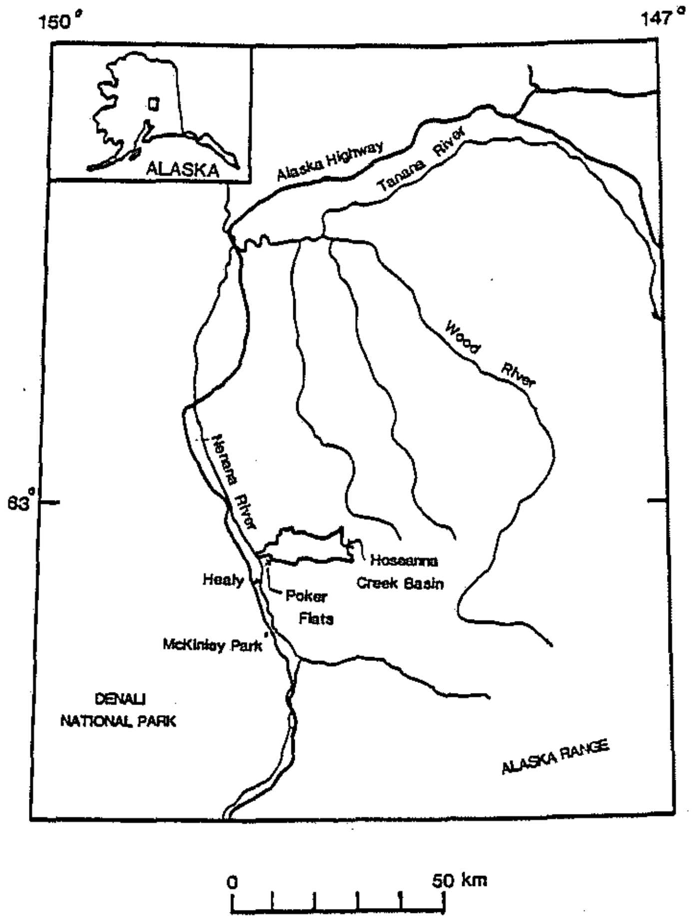

Figure 1. Location map. Hoseanna Creek is a small tributary of the Nenana River in central Alaska.

schist basement is the mid-Tertiary coal-bearing Usibelli Group which, in turn, is overlain by the late Tertiary Nenana Gravel (Wahrhaftig, 1986). The Tertiary formations are poorly lithified sediments. The east and west ends of the watershed are thinly mantled by Quaternary stream gravels and alluvium (Wahrhaftig, 1958). These gravels appear to protect the underlying sediments from erosion, possibly because infiltration rates are high enough to significantly reduce peak runoff rates. Generally, the Tertiary sedimentary formations strike east-west and dip to the north at 5 to 25° (Wahrhaftig, 1970).

The schist is the most resistant rock type in the basin. Schist, which is only exposed in the south side of the basin, has the highest overall elevation and has a north facing aspect (Figure 2). Most of the schist terrain is covered by a thin tundra mat that is susceptible to solifluction. At higher elevations frost shattered rubble is common.

The weakly consolidated coal-bearing group is comprised of sandstone, silt, clay and coal sequences (Wahrhaftig, 1986). Areas underlain by the coal-bearing formations are the lowest in elevation and form the

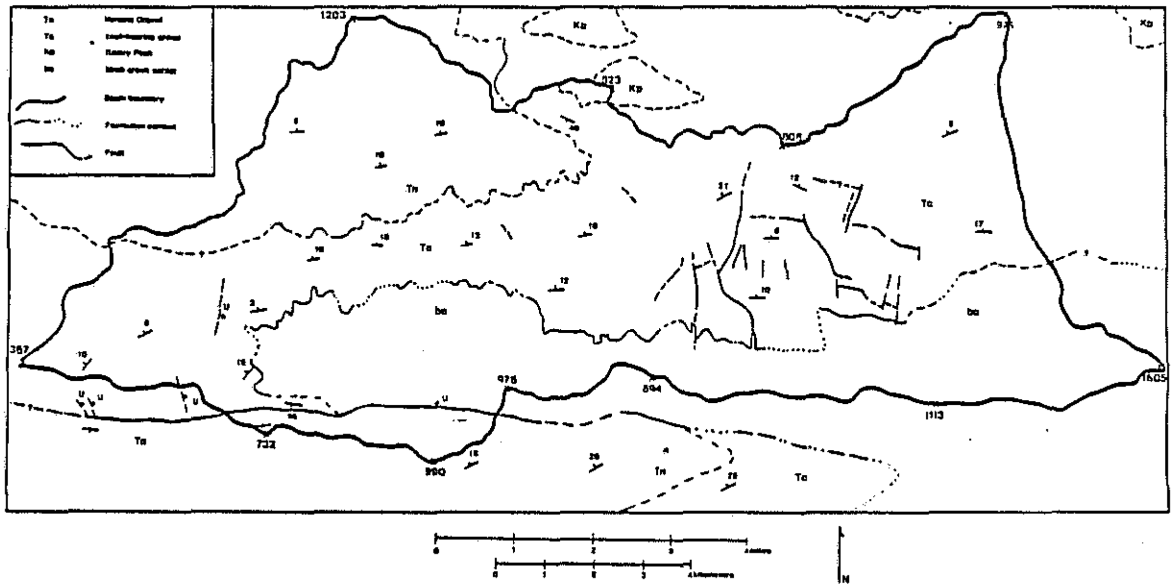

Figure 2. Geology of Hoseanna Creek watershed. Three major lithologies occur in the basin: the Birch Creek schist, the coal-bearing Usibelli Group and the Nenana Gravel. Generally, strata strike east-west and dip to the north. Strike and dip symbols are shown with dip angle next to them. Faulting is primarily in the coal-bearing group, except a high angle reverse fault borders the southern divide. Elevations (meters) in the south are generally higher than in the north. (After Wahrhaftig, 1970)

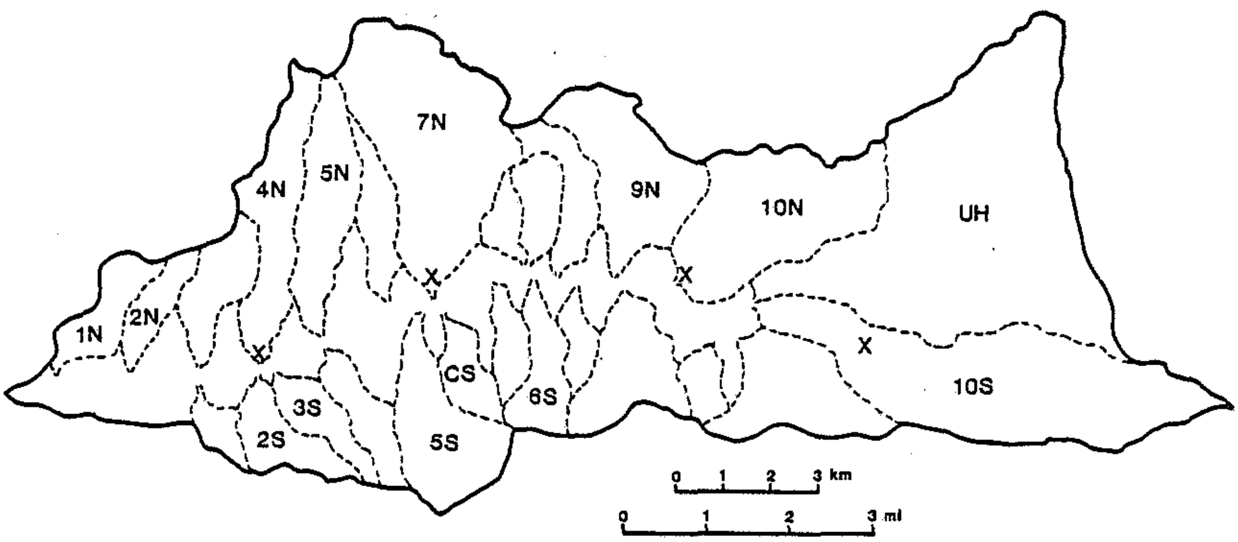

Figure 3. Hoseanna Creek watershed divided into 26 sub-basins. The 14 basins marked by number-letter symbol were chosen to represent the variation of sediment production within the basin and the variation from lithology to lithology. The "X"'s mark the location of Alaska Division of Geological and Geophysical Surveys' stream monitoring sites.

trunk of the basin (Figure 2). Landslides commonly form in this group if the strata are dipping toward a stream cut; if strata dip away from the stream cut, steep unvegetated cliffs or "badlands" may form. Both of these landforms are prolific sediment producers. About 5% of the Usibelli Group is exposed by these distinctive badlands, and over 9% is covered by landslide deposits.

Overlying the coal bearing group is the poorly consolidated Nenana Gravel. This formation has a distinct orange-brown outcrop color and is composed mainly of large cross-bedded coarse-grained sandstone and thick gravel sequences (Wahrhaftig, 1986). Over 20% of the Nenana Gravel is badlands in some form of development, but only one significant landslide is found in this lithology.

METHODS

Hoseanna Creek watershed was divided into 26 major sub-basins of which 14 were choosen to represent the sediment production variations within the basin. These 14 sub-basins comprised 68% of the total basin area. For identification each sub-basin was assigned a number according to its order going upstream and whether it was on the north or south side of the main channel (i.e. 1N, 2N, 3N ..., 1S, 2S, 3S...) (Figure 3). This sub-basin map was overlain onto a geologic map (Wahrhaftig, 1970) from which the percent lithology in each sub-basin was determined (Table 1).

Table 1. Percentage of each lithology in each sub-basin. Sub-basin locations are shown on Figure 3.

Sub-basin (#)	Area (km^2)	Quaternary gravel (%)	Nenana Gravel (%)	Usibelli Group (%)	Birch Creek schist (%)
1N	1.79	46.8	1.7	51.5	---
2N	1.58	57.1	6.5	36.3	---
4N	4.41	24.3	55.1	20.2	0.4
5N	4.04	23.1	56.4	19.4	1.1
7N	10.73	16.1	71.7	12.2	---
9N	5.39	---	2.7	92.4	4.9
10N	8.11	---	---	100.0	---
2S	2.07	8.5	32.8	30.8	27.9
3S	1.79	3.3	18.8	2.3	75.6
5S	4.64	3.4	33.2	0.4	63.0
6S	2.18	0.2	---	27.1	72.7
10S	13.63	3.2	---	16.1	80.7
CS	1.63	1.0	---	---	99.0
UH	22.37	10.2	---	82.5	7.3

Frances (4N), Popovitch (7N), North Hoseanna (10N) and Sanderson ical and Geophysical Surveys (A.D.G.G.S) (Mack, 1987). Frances, North Hoseanna and Sanderson Creeks have automated crest stage suspended sediment samplers and continuous recording stream gauges. A.D.G.G.S. has sampled bed load at Popovitch Creek where it comprises the majority of the total sediment load (Mack, 1987). Each of the 10 remaining sub-basins were visited during high and low runoff events. At the time of discharge measurements suspended sediment samples were taken by hand (grab samples) into 300 ml bottles from the channel center. Grab samples were also taken at the A.D.G.G.S. automated sampler sites while the samplers were operating, allowing the grab samples to be directly compared with the A.D.G.G.S. results. Samples were evaporated to determine total suspended sediment content. Data from the 14 sites were used to compute sediment production equations of the form:

$$T_s = b\ Q^m \quad \text{or} \quad \log (T_s) = m \log (Q) + b$$

where:

T_s = total suspended sediment, including dissolved load, in g/l.

b = a constant that varies for each creek and each year. It is determined from a best fit regression line of log (T_s) and log (Q). It is the y-intercept of this line.

Q = discharge in ft^3/s.

m = a constant that varies for each creek and each year. It is also determined from a best fit regression line of log (T_s) and log (Q). It is the slope of this line.

It was found that the creeks had greater average discharges in 1986 than in 1987, but 1987 had higher sediment concentrations for any given flow rate. This meant that if data from both summer 1986 and summer 1987 were combined and a regression line was fit to the combined data set inaccurate regression slopes would often occur. If the different years' data were treated separately, more accurate regression line slopes resulted, but 1987 regression lines generally had higher y-intercepts (Table 2). Figure 4 shows four examples in which separate lines were fit to each years' data. The increased sediment concentrations in 1987 are believed to be due to a sparse snow pack and therefore more frost disturbance during the 1986-87 winter. Less runoff from snow melt and rain probably also contributed to this difference.

An attempt was made to determine what effect a given storm would have on the sediment production of each basin. The 1.25 year flood discharge ($Q_{1.25}$) was computed using the equations of Lamke (1978). These discharges were then used in the sediment discharge equations established above to determine peak total suspended sediment (g/l) for the this flood in each sub-basin. The 1.25 year flood was chosen to represent the normal peak discharge for each creek. It was not warranted to extrapolate the sediment production equations beyond the 1.25 year

Table 2. Regression line constants for each sub-basin for each year. [$\log T_s = m \log (Q) + b$]

Sub-basin (#)	1986 No. of data Points	1986 slope (m)	1986 y-intrcpt. (b)	1987 No. of data points	1987 slope (m)	1987 y-intrcpt. (b)
1N	---	---	---	5	0.80	0.54
2N	---	---	---	4	1.92	20.42
4N	16	1.99	2.79	---	---	---
5N	3	1.29	8.32	7	1.17	18.9
7N	6	1.55	2.29	---	---	---
9N	3	0.68	0.50	6	1.73	0.51
10N	7	0.91	0.71	---	---	---
2S	2	0.89	1.58	3	0.53	4.27
3S	2	1.31	0.71	4	0.46	2.00
5S	3	0.21	0.23	6	0.60	0.63
6S	---	---	---	5	1.31	3.67
10S	---	---	---	3	0.58	0.66
CS	2	0.80	0.16	3	0.64	0.52
UH	4	1.45	0.01	4	1.23	0.09

event until more data are available. Calculated sediment concentrations from this storm varied between 1.0 g/l to 348 g/l. We feel sediment concentrations in excess of 50 g/l are unrealistic. During two very high flow events experienced during summer 1986, maximum concentrations were between 40 and 50 g/l. These two events were probably on the order of 5- or 10-year events so maximum sediment concentrations were set at 50 g/l.

Peak sediment concentrations alone do not accurately indicate what effect any given storm has on the various sub-basins. To establish an index of which sub-basins are eroding slowly and which are eroding quickly, the peak sediment discharge rate (g/s) was divided by the area (m^2) and the density (g/m^3) of the eroded material (sediments or schist) in each respective basin to determine an "erosion rate" (m/s) for each sub-basin where peak sediment discharge rate is the product of the peak 1.25 year discharge (m^3/s) and the peak sediment concentration (g/m^3) during this event. The "erosion rate" so calculated does not account for differences in total sediment produced during the 1.25 year storm since differences in hydrographs were not accounted for, but it is thought to be a reasonable index of erosion rate differences between sub-basins (Table 3).

Drainage density for each lithology was determined from blow ups of U.S.G.S. 1:63,360 scale maps (Table 4). Since most sub-basins were underlain by more than one lithology the sub-basins had to be divided into smaller basins that contained only one lithology. These smaller basins were typically drained by third order streams.

Table 3. Sediment production rate or "erosion rate" during the peak of the 1.25 year runoff event. This runoff event has an 80% chance of being exceeded in any given year. Sediment concentration was calculated using the values in Table 2 and the equation: $\log(T_s) = m \log(Q_{1.25}) + b$ where $Q_{1.25}$ is the peak discharge rate during the 1.25 year runoff event. Sediment concentration was calculated using 1986 data and using 1987 constants. The sediment concentration shown below is the average of these two numbers. Peak discharge was calculated from the method of Lamke (1978). Calculation of erosion rate is described in the text.

Sub-basin (#)	1.25 yr runoff, $Q_{1.25}$ (m^3/s, (ft^3/s))	Sed. conc., T_s (g/l)	Erosion rate, E (10^{-9} m/s)
1N	0.13 (4.6)	1.5	0.05
2N	0.11 (4.0)	50.0 (137*)	1.64
4N	0.32 (11.3)	50.0 (348*)	1.66
5N	0.30 (10.7)	50.0 (187*)	1.71
7N	0.92 (32.5)	50.0 (79*)	1.96
9N	0.47 (16.5)	34.3	1.36
10N	0.75 (26.6)	14.1	0.60
2S	0.19 (6.7)	10.2	0.43
3S	0.17 (6.0)	6.0	0.26
5S	0.43 (15.1)	1.8	0.08
6S	0.20 (7.0)	47.2	1.96
10S	1.42 (50.0)	6.4	0.38
CS	0.15 (5.3)	1.0	0.04
UH	2.14 (75.5)	11.5	0.50

* These are the calculated sediment concentrations for these four basins. Concentrations greater than 50.0 g/l are thought to be excessive for reasons outlined in the text.

Table 4. Relation of lithology with average erosion rate and drainage density. For each lithology, the product of the calculated erosion rate (Table 3) and the area of each lithology in each sub-basin were summed and divided by the the total area of the given lithology in all 14 sub-basins to determine average erosion rate.

Lithology	Average erosion rate (10^{-9} m/s)	Drainage density (km/km^2)
Birch Creek schist	0.41	8.1
Usibelli Group	0.74	9.9
Nenana Gravel	1.57	12.2

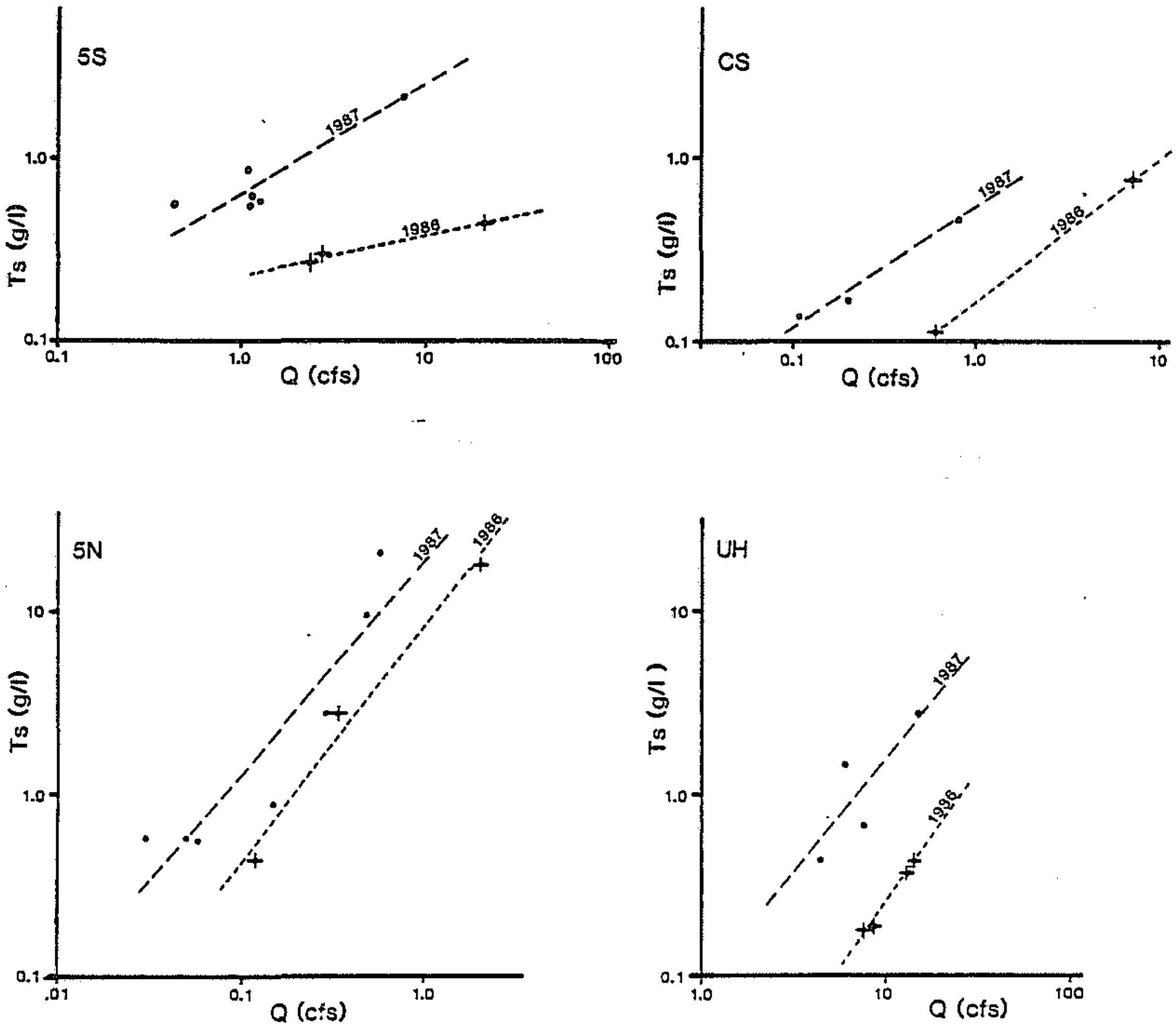

Figure 4. Four examples of the regressions of discharge (Q) and total suspended sediment (T_S). Generally, southern sub-basins are underlain by schist and have comparitively flat regression lines (e.g. CS, 5S), while northern sub-basins, which are commonly underlain by weak sandstone and gravel formations, have steep regression lines (e.g. 5N, UH). Note also that for any given flow rate 1987 had greater sediment concentrations than 1986.

RESULTS

Lithology

The percent area covered by each lithology in each sub-basin was computed and is shown in Table 1. Of the 14 sub-basins monitored, 3 are underlain primarily by schist (CS, 5S, and 10S), 5 by the coal bearing group (1N, 2N, 9N, 10N and UH) and 3 by the Nenana Gravel (4N, 5N and 7N). The remaining sub-basins (2S, 3S and 6S) are underlain by large portions of more than one lithology (Figures 2 and 3).

Sediment Production

Basins that produce large quantities of sediment have steep regression lines (Figure 4). Table 2 summarizes the regression line constants (slope and intercept) for each basin and each year. For sub-basins with roughly the same area, the lowest sediment production is occuring primarily from the resistant schistose sub-basins (CS, 2S, 3S, 5S and 10S) while the highest production is occuring primarily from the sub-basins underlain by the poorly consolidated sandstone and gravel formations (2N, 4N, 5N, 7N, 9N, 10N and UH) (Figure 5). Sub-basins 1N and 6S are exceptions. Schist underlies 73% of the 6S sub-basin, but 6S is still a high sediment producer because the last kilometer of its streamcourse flows over a very active landslide which occurs in the coal-bearing group. In contrast, 1N is underlain entirely by the soft Tertiary formations but shows a low sediment production rate. This stream is very accessible and was visually observed several times during every storm event but never showed high discharges. These subdued runoff peaks are thought to be due to the flat lying permeable Quaternary gravels that mantle nearly half the sub-basin. These gravels probably also serve to protect the underlying sediments from erosion..

The sediment production rate or "erosion rate" calculated from the 1.25 year runoff event for each basin is summarized in Table 3. Despite limiting peak sediment concentration to 50 g/l these rates vary by a factor of 50! Again, the highest rates occur in the basins that are underlain by the sandy coal-bearing and gravel formations, and the lowest rates occur in the schistose sub-basins. Basins 1N and 6S are again exceptions because 1N is mantled by Quaternary gravels and the lower reaches of 6S flows over an active landslide.

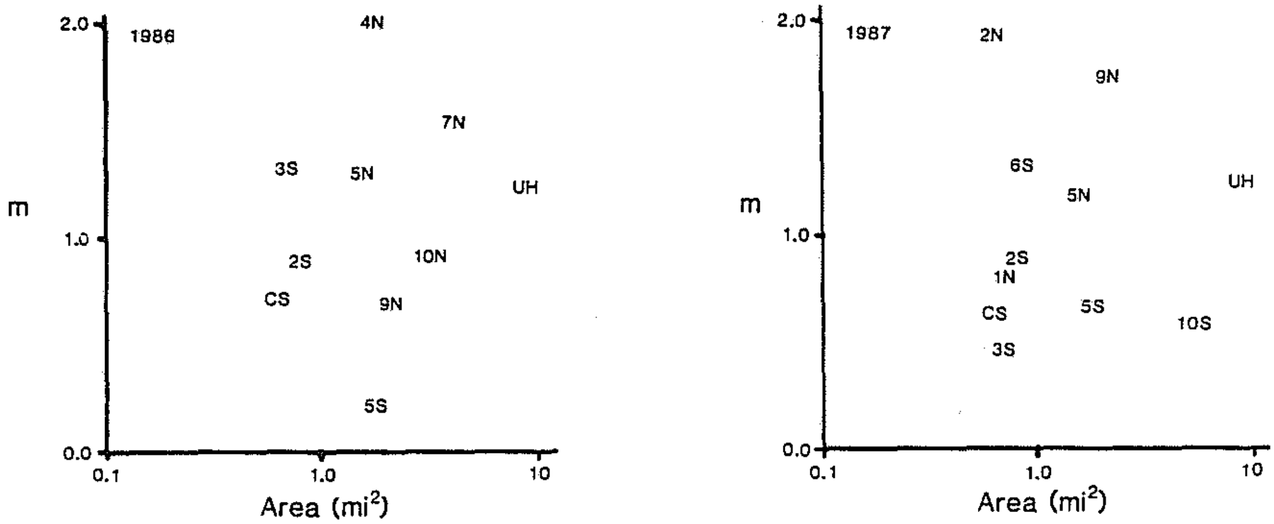

Figure 5. Sub-basin area versus the slope of the basin's regression line for 1986 and 1987. Note that the sandstone and gravel containing basins in the north generally have higher regression line slopes for a given basin area than the schist containing basins to the south.

Drainage Density

The results of the drainage density analysis are summarized in Table 4. As expected, drainages in the resistant schist generally have the lowest densities (average 8.1 km/km^2); streams in the coal-bearing group have higher densities (9.9 km/km^2), and Nenana Gravel basins have the highest densities (12.2 km/km^2).

Summary

Table 4 shows the relationship between lithology, average erosion rate and drainage density in condensed form. The method by which average erosion rate for each lithology was calculated is described in Table 4. Sub-basins with a high percentage of Nenana Gravel have high sediment production rates and high densities, while the Birch Creek schist sub-basins exhibit the lowest sediment production rates and the lowest stream densities. Basins underlain primarily by the coal-bearing Usibelli Group have moderate stream densities and moderate to high sediment production rates.

CONCLUSIONS

The results presented here indicate that the Tertiary sedimentary lithologies in the Hoseanna Creek Basin are eroding at an accelerated rate when compared to a more normal rock type such as the Birch Creek schist. These erosion rates appear to be, on the average, about 2-4 times faster than the Birch Creek schist erosion rate (Table 4) and as much as 50 times greater for individual basins (Table 3). These higher erosion rates are reflected in the geomorphology of each lithologic type in that high drainage densities correlate directly with high sediment production and erosion rates (Table 4).

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